NUREG/CR-5250
UCID-21517
Vol. 6

Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains

Regional Comparison Between Sites, Site Effects, General Discussion, and Conclusions

Prepared by D.L. Bernreuter, J.B. Savy, R.W. Mensing, J.C. Chen

Lawrence Livermore National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555

2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7082

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations,* and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Information Support Services, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-5250
UCID-21517
Vol. 6

Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains

Regional Comparison Between Sites, Site Effects, General Discussion, and Conclusions

Manuscript Completed: November 1988
Date Published: January 1989

Prepared by
D.L. Bernreuter, J.B. Savy, R.W. Mensing, J.C. Chen

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

Prepared for
Division of Engineering and System Technology
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN A0448

Abstract

The EUS Seismic Hazard Characterization Project (SHC) is the outgrowth of an earlier study performed as part of the U.S. Nuclear Regulatory Commission's (NRC) Systematic Evaluation Program (SEP). The objectives of the SHC were: (1) to develop a seismic hazard characterization methodology for the region east of the Rocky Mountains (EUS), and (2) the application of the methodology to 69 site locations, some of them with several local soil conditions. The method developed uses expert opinions to obtain the input to the analyses. An important aspect of the elicitation of the expert opinion process was the holding of two feedback meetings with all the experts in order to finalize the methodology and the input data bases. The hazard estimates are reported in terms of peak ground acceleration (PGA) and 5% damping velocity response spectra (PSV).

A total of eight volumes make up this report which contains a thorough description of the methodology, the expert opinion's elicitation process, the input data base as well as a discussion, comparison and summary volume (Volume VI).

Consistent with previous analyses, this study finds that there are large uncertainties associated with the estimates of seismic hazard in the EUS, and it identifies the ground motion modeling as the prime contributor to those uncertainties.

The data bases and software are made available to the NRC and to public uses through the National Energy Software Center (Argonne, Illinois).

Table of Contents
Volume VI

List of Tables and Figures

PAGE

Foreword

The impetus for this study came from two unrelated needs of the Nuclear Regulatory Commission (NRC). One stimulus arose from the NRC funded "Seismic Safety Margins Research Programs" (SSMRP). The SSMRP's task of simplified methods needed to have available data and analysis software necessary to compute the seismic hazard at any site located east of the Rocky Mountains which we refer to as the Eastern United States (EUS) in a form suitable for use in probabilistic risk assessment (PRA). The second stimulus was the result of the NRC's discussions with the U.S. Geological Survey (USGS) regarding the USGS's proposed clarification of their past position with respect to the 1886 Charleston earthquake. The USGS clarification was finally issued on November 18, 1982, in a letter to the NRC, which states that:

> "Because the geologic and tectonic features of the Charleston region are similar to those in other regions of the eastern seaboard, we conclude that although there is no recent or historical evidence that other regions have experienced strong earthquakes, the historical record is not, of itself, sufficient ground for ruling out the occurrence in these other regions of strong seismic ground motions similar to those experienced near Charleston in 1886. Although the probability of strong ground motion due to an earthquake in any given year at a particular location in the eastern seaboard may be very low, deterministic and probabilistic evaluations of the seismic hazard should be made for individual sites in the eastern seaboard to establish the seismic engineering parameters for critical facilities."

Anticipation of this letter led the Office of Nuclear Reactor Regulation to jointly fund a project with the Office of Nuclear Regulatory Research. The results were presented in Bernreuter et. al., (1985), and the objectives were:

1. to develop a seismic hazard characterization methodology for the entire region of the United States east of the Rocky Mountains.

2. to apply the methodology to selected sites to assist the NRC staff in their assessment of the implications in the clarification of the USGS position on the Charleston earthquake, and the implications of the occurrence of the recent earthquakes such as that which occurred in New Brunswick, Canada, in 1982.

The methodology used in that 1985 study evolved from two earlier studies that the Lawrence Livermore National Laboratory (LLNL) performed for the NRC. One study, Bernreuter and Minichino (1983), was part of the NRC's Systematic Evaluation Program (SEP) and is simply referred hereafter to as the SEP study. The other study was part of the SSMRP.

At the time (1980-1985), an improved hazard analysis methodology and EUS seismicity and ground motion data set were required for several reasons:

o Although the entire EUS was considered at the time of the SEP study, attention was focused on the areas around the SEP sites--mainly in

the Central United States (CUS) and New England. The zonation of other areas was not performed with the same level of detail.

- o The peer review process, both by our Peer Review Panel and other reviewers, identified some areas of possible improvements in the SEP methodology.

- o Since the SEP zonations were provided by our EUS Seismicity Panel in early 1979, a number of important studies had been completed and several significant EUS earthquakes had occurred which could impact the Panel members' understanding of the seismotectonics of the EUS.

- o Our understanding of the EUS ground motion had improved since the time the SEP study was performed.

By the time our methodology was firmed up, the expert opinions collected and the calculations performed (i.e. by 1985), the Electric Power Research Institute (EPRI) had embarked on a parallel study.

We performed a comparative study, Bernreuter et. al., (1987), to help in understanding the reasons for differences in results between the LLNL and the EPRI studies. The three main differences were found to be: (1) the minimum magnitude value of the earthquakes contributing to the hazard in the EUS, (2) the ground motion attenuation models, and (3) the fact that LLNL accounted for local site characteristics and EPRI did not. Several years passed between the 1985 study and the application of the methodology to all the sites in the EUS. In recognition of the fact that during that time a considerable amount of research in seismotectonics and in the field of strong ground motion prediction, in particular with the development of the so called random vibration or stochastic approach, NRC decided to follow our recommendations and have a final round of feedback with all our experts prior to finalizing the input to the analysis.

In addition, we critically reviewed our methodology which lead to minor improvements and we also provided an extensive account of documentation on the ways the experts interpreted our questionnaires and how they developed their answers. Some of the improvements were necessitated by the recognition of the fact that the results of our study will be used, together with results from other studies such as the EPRI study or the USGS study, to evaluate the relative hazard between the different plant sites in the EUS.

This report includes eight volumes:

Volume I provides an overview of the methodology we developed for this project. It also documents the final makeup of both our Seismicity and Ground Motion Panels, and documents the final input from the members of both panels used in the analysis. Comparisons are made between the new results and previous results.

Volumes II to V provide the results for all the active nuclear power plant sites of the EUS divided into four batches of approximately equal size and of sites roughly located in the four main geographical regions of the EUS

(NE,1 SE, NC and SC). A regional discussion is given in each of Vols. II to V.

Volume VI emphasizes important sensitivity studies, in particular the sensitivity of the results to correction for local site conditions and G-Expert 5's ground motion model. It also contains a summary of the results and provides comparisons between the sites within a common region and for sites between regions.

Volume VII contains unaltered copies of the ten questionnaires used from the beginning of the 1985 study to develop the complete input for this analysis.

After the bulk of the work was completed and draft reports for Vols. I-VII were written, additional funding became available.

Volume VIII contains the hazard result for the 12 sites which were primarily rock sites but which also had some structures founded on shallow soil. These results supplement the results given in Vols. II to V where only the primary soil condition at the site was used.

List of Abbreviations and Symbols

A	Symbol for Seismicity Expert 10 in the figures displaying the results for the S-Experts
ALEAS	Computer code to compute the BE Hazard and the CP Hazard for each seismicity expert
AM	Arithmetic mean
AMHC	Arithmetic mean hazard curve
B	Symbol for Seismicity Expert 11 in the figures displaying the results for the S-Experts
BE	Best estimate
BEHC	Best estimate hazard curve
BEUHS	Best estimate uniform hazard spectrum
BEM	Best estimate map
C	Symbol for Seismicity Expert 12 in the figures displaying the results for the S-Experts
COMAP	Computer code to generate the set of all alternative maps and the discrete probability density of maps
COMB	Computer code to combine BE hazard and CP hazard over all seismicity experts
CP	Constant percentile
CPHC	Constant percentile hazard curve
CPUHS	Constant percentile uniform hazard spectrum
CUS	Central United States, roughly the area bounded in the west by the Rocky Mountains and on the east by the Appalachian Mountains, excluding both mountain systems themselves
CZ	Complementary zone
D	Symbol for Seismicity Expert 13 in the figures displaying the results for the S-Experts
EPRI	Electric Power Research Institute

EUS	Used to denote the general geographical region east of the Rocky Mountains, including the specific region of the Central United States (CUS)
g	Measure of acceleration: 1g = 9.81m/s/s = acceleration of gravity
G-Expert	One of the five experts elicited to select the ground motion models used in the analysis
GM	Ground motion
HC	Hazard curve
I_o	Epicentral intensity of an earthquake relative to the MMI scale
I_s	Site intensity of an earthquake relative to the MMI scale
LB	Lower bound
LLNL	Lawrence Livermore National Laboratory
M	Used generically for any of the many magnitude scales but generally m_b, $m_b(Lg)$, or M_L.
M_L	Local magnitude (Richter magnitude scale)
M_b	True body wave magnitude scale, assumed to be equivalent to $m_b(Lg)$ (see Chung and Bernreuter, 1981)
$m_b(Lg)$	Nuttli's magnitude scale for the Central United States based on the Lg surface waves
M_S	Surface wave magnitude
MMI	Modified Mercalli Intensity
M_o	Lower magnitude of integration. Earthquakes with magnitude lower than M_o are not considered to be contributing to the seismic hazard
NC	North Central; Region 3
NE	North East; Region 1
NRC	Nuclear Regulatory Commission
PGA	Peak ground acceleration
PGV	Peak ground velocity
PRD	Computer code to compute the probability distribution of epicentral distances to the site

PSRV Pseudo relative velocity spectrum. Also see definition of spectra below

Q Seismic quality factor, which is inversely proportional to the inelastic damping factor.

Q1 Questionnaire 1 - Zonation (I)

Q2 Questionnaire 2 - Seismicity (I)

Q3 Questionnaire 3 - Regional Self Weights (I)

Q4 Questionnaire 4 - Ground Motion Models (I)

Q5 Questionnaire 5 - Feedback on seismicity and zonation (II)

Q6 Questionnaire 6 - Feedback on ground motion models (II)

Q7 Questionnaire 7 - Feedback on zonation (III)

Q8 Questionnaire 8 - Seismicity input documentation

Q9 Questionnaire 9 - Feedback on seismicity (III)

Q10 Questionnaire 10 - Feedback on ground motion models (III)

R Distance metric, generally either the epicentral distance from a recording site to the earthquake or the closest distance between the recording site and the ruptured fault for a particular earthquake.

Region 1 (NE): North East of the United States, includes New England and Eastern Canada

Region 2 (SE): South East United States

Region 3 (NC): North Central United States, includes the Northern Central portions of the United States and Central Canada

Region 4 (SC): Central United States, the Southern Central portions of the United States including Texas and Louisiana

RP Return period in years.

RV Random vibration. Abbreviation used for a class of ground motion models also called stochastic models.

S Site factor used in the regression analysis for G-Expert 5's GM model: $S = 0$ for deep soil, $S = 1$ for rock sites

SC South Central; Region 4

SE South East; Region 2

S-Expert	One of the eleven experts who provide the zonations and seismicity models used in the analysis
SEP	Systematic Evaluation Program
SHC	Seismic Hazard Characterization
SHCUS	Seismic Hazard Characterization of the United States
SN	Site Number
Spectra	Specifically in this report: attenuation models for spectral ordinates were for 5% damping for the pseudo-relative velocity spectra in PSRV at five frequencies (25, 10, 5, 2.5, 1 Hz).
SSE	Safe Shutdown Earthquake
SSI	Soil-structure-interaction
SSMRP	Seismic Safety Margins Research Program
UB	Upper bound
UHS	Uniform hazard spectrum (or spectra)
USGS	United States Geological Survey
WUS	The regions in the Western United States where we have strong ground motion data recorded and analyzed

Executive Summary: Volume VI

Volume VI is one of eight volumes comprised in the reporting of this study. In this volume we discuss the important sensitivities found in the course of our analysis, we make regional comparisons between sites and summarize the conclusions we have reached.

In Section 2 we give a discussion of the sensitivity of the computed seismic hazard to several important aspects of the methodology used to estimate the ground motion. First, in Section 2.2 we present the results of a sensitivity study to show the effect that site correction has on the hazard. We selected the Limerick site and performed the analysis assuming that the site fell into each of our eight soil categories. We then compared the results from these eight separate analyses. This comparison gives the effect of site type on the hazard at the Limerick site. In an effort to generalize from these results, we found three pairs of sites that are distant from the Limerick site but each pair are relatively close together and have different site categories. By comparing the effect of site type on the hazard observed at these sites to the effect of site type observed as part of our sensitivity study using the Limerick site, we reached the conclusion that there did not appear to be a significant variation in the effect of site type introduced by the region the site is located in.

This point is re-examined in Vol. VIII and summarized in Section 2 of Vol. VI where it is confirmed that the amount of variation from the expected value varies with the regional location of the site. However, this amount of variation was not found to be greater than 10 percent at the 12 sites analyzed. We also emphasize the dangers of reasoning in terms of probabilities of exceedance, since comparable variations in PGA between two sites could translate into drastically different amounts of variation in the probabilities of exceedance, due to the different slopes of the hazard curves.

In Section 2.3 we revisited the sensitivity of the results to the inclusion or non-inclusion of G-Expert 5's ground motion model. We identified four categories of sites: (1) rock with the hazard from distant zones with large earthquakes, (2) rock with the hazard primarily from local zones, (3) same as (1) except a soil site, and (4) same as (2) except a soil site. We found that the results were most sensitive to the inclusion or non-inclusion of G-Expert's 5 ground motion model for category (1), then followed by decreasing sensitivity for category (2), then category (3) and least sensitivity for category (4). Interestingly, we found the sensitivity of the median to the inclusion/non-inclusion of G-Expert 5's model was about the same for all four categories of sites.

In Section 2.4 we examined the reasons why our constant percentile uniform hazard spectra seemed to be high relative to the hazard curve for PGA. We concluded that the apparent disconnect between the PGA hazard and the spectral hazard was due to the correction for EUS conditions introduced into some of the ground motion models. These corrections suggest that typical EUS earthquakes have significantly more high frequency motion than assumed in either the R.G. 1.60 spectrum or the NUREG-0098 spectrum.

In Section 3 we compare the results between all sites. At the 0.2g level we found that typically at any site there is over two orders of magnitude uncertainty in the estimate of hazard (as measured by the difference between the 15th and 85th percentiles CPHCs). We also found that the spread of the median probability of exceeding 0.2g PGA between the site with the lowest hazard and the site with the highest hazard is about 1.4 orders of magnitude.

We did not find large differences in the hazard between sites located at approximately the same distance (approximately 200 km) from the New Madrid seismic zone, as with sites located approximately the same distance from the Charleston seismic zone. We did find that the makeup of the hazard was different with nearby zones being more important for sites near the Charleston seismic zone than for sites near the New Madrid zones. Conversely, large distant earthquakes were more important for the New Madrid site than for the Charleston site.

We found that, <u>of the sites analyzed</u>, some sites in New England had the highest hazard. But it must be noted that the sites affected by the New Madrid and Charleston earthquake were at some distance from the source zones. Thus, if a site were to be located near these source zones, the hazard would be greater than found for the New England sites.

Some regional influence could be seen in the spectral shape, particularly at the longer periods. The spectral shapes for the sites near the New Madrid region had more long period energy than for sites located near Charleston or in New England. There were some differences at the short period end of the spectrum, but it was relatively small.

In Section 4 we present a number of conclusions reached during the course of this study, the most important of which are:

- Our estimates of the seismic hazard for any site in the EUS have large uncertainties at some sites. Most individual experts have expressed significant uncertainties about their input. There is also a wide diversity in the opinion among experts.

- The median estimate of the seismic hazard appears to be relatively stable, both in time and between studies performed without systematic differences.

- Correction for local soil conditions is important and has a significant impact on the results.

- The results, particularly the arithmetic mean and best estimate estimators, are very sensitive to ground motion models with low attenuation, e.g., such as the model selected by G-Expert 5.

- There is a significant variation in the hazard across the EUS; e.g., the median estimate for the 10,000 year return period for the PGA varies from 0.08g to 0.33g.

1. INTRODUCTION

In Vol. I of this report, we provide a discussion of our methodology and the input provided by both our S and G-Experts. In Vols. II-V, we provided the results of our analysis of the seismic hazard for all of the active Eastern United States (EUS) nuclear power plant sites using our methodology and the input from our experts.

In writing this volume (Vol. VI) we have assumed that the reader had read Vol. I and any one of Vols. II-V. In Section 2 of this volume we give a discussion of the sensitivity of the results presented in Vols. II-V to several important aspects of the methodology we used to estimate the ground motion.

In each of the Vols. II-V we included a section where comparisons were made between the sites included in the volume. In Section 3 of this volume we make comparisons between all sites and regions. In Section 4 we summarize the conclusions we have reached at the end of this study.

Volume VII gives all of the questionnaires answered by our experts. The experts responses to these questionnaires form the basis for input data needed by our computer programs to compute the seismic hazard at each site.

Volume VIII provides additional analysis to account for the hazard at sites where critical structures are founded on several soil categories.

As discussed in Vol. I, the 69 active nuclear power plant sites were divided into four batches - roughly along regional lines. However, in order to have approximately four equal sets, the sites in batch 4 did not correspond to a single region. In Tables 1.1a to 1.1d we list all of the sites included in each of the Volumes of this report and in Figs. 1.1a, b, c, d we provide maps giving the location of each of the sites. In Fig. 1.2 we provide a figure with all of the sites (unlabeled) located on it to establish the relative location between the sites and other points of interest.

In Section 2 of this Volume we examine the sensitivity of the computed seismic hazard to several important aspects of the methodology used to estimate the ground motion. In previous Volumes we have indicated the significance of correction introduced to model the local soil conditions at various sites. In Section 2.2 we give the results of a sensitivity study of the effect of our methodology for site correction on the hazard estimates. In addition, we provide a discussion on the amount of ground motion amplification in the PGA values between shallow and rock site conditions at the 12 sites which include both rock and shallow soil conditions (see Vol. VIII).

In previous Volumes we have noted the sensitivity of the hazard at some rock sites to the ground motion model selected by G-Expert 5. In Section 2.3 we explore this issue in detail.

In Section 2.4 we discuss the implication on the hazard of the correction that has been introduced into some ground motion models heavily weighted by G-Experts to "correct" them for use in the EUS.

In Section 3 we compare the estimated hazard between sites and discuss regional variations in the estimated hazard.

In Section 4 we summarize the main results and conclusions reached in this study.

TABLE 1.1a

SITES AND SOIL CATEGORY USED FOR EACH SITE IN BATCH 1

	SITE NAME	MAP (1) KEY	SOIL CATEGORY (2)
1.	Fitzpatrick	1	Rock
2.	Ginna	2	Rock
3.	Haddam Neck	3	Rock
4.	Hope Creek	4	Deep Soil
5.	Indian Point	5	Rock
6.	Limerick	6	Rock
7.	Maine Yankee	7	Rock
8.	Millstone	8	Rock
9.	Nine Mile Pt.	9	Rock **
10.	Oyster Creek	A	Deep Soil
11.	Peach Bottom	B	Rock
12.	Pilgrim	C	Sand-Like 2
13.	Salem	D	Deep Soil
14.	Seabrook	E	Rock
15.	Shoreham	F	Deep Soil
16.	Susquehanna	G	Rock**
17.	Three Mile Island	H	Rock**
18.	Vermont Yankee	I	Rock
19.	Yankee at Rowe	J	Till- Like 2

(1) Key used on Fig. 1.1a

(2) Site categories are given in Table 3.9 of Vol. I and repeated in Table 1.2.

(**) Have some structures founded on shallow soil.

TABLE 1.1b

SITES AND SOIL CATEGORY USED FOR EACH SITE IN BATCH 2

	SITE NAME	Map (1) KEY	SOIL CATEGORY
1.	Bellefonte	1	Rock
2.	Browns Ferry	2	Rock **
3.	Brunswick	3	Till-like 2
4.	Calvert Cliffs	4	Deep soil
5.	Catawba	5	Rock **
6.	Farley	6	Rock **
7.	Hatch	7	Deep soil
8.	McGuire	8	Rock
9.	North Anna	9	Rock **
10.	Oconee	A	Rock **
11.	Robinson	B	Deep soil
12.	Sequoyah	C	Rock
13.	Shearon Harris	D	Rock
14.	Summer	E	Rock **
15.	Surry	F	Deep soil
16.	Vogtle	G	Deep soil
17.	Watts Bar	H	Rock

(1) Key used on Fig. 1.1b.

(**) Have some structures founded in shallow soil.

TABLE 1.1c

SITES AND SOIL CATEGORY USED FOR EACH SITE
IN BATCH 3

	SITE NAME	Map (1) KEY	SOIL CATEGORY
1.	Beaver Valley	1	Sand-like 1
2.	Big Rock Point	2	Till-like 1
3.	Braidwood	3	Rock
4.	Byron	4	Rock
5.	Clinton	5	Till-like 2
6.	Cook	6	Sand-like 2
7.	Davis Besse	7	Rock
8.	Dresden	8	Rock
9.	Fermi	9	Rock
10.	Kewaunee	A	Till-like 2
11.	LaSalle	B	Till-like 2
12.	Palisades	C	Sand-like 2
13.	Perry	D	Rock
14.	Point Beach	E	Till-like 1
15.	Quad Cities	F	Rock
16.	Zion	G	Sand-like 2

(1) Key used on Fig. 1.1c.

(**) Have some structures founded in shallow soil.

TABLE 1.1d

SITES AND SOIL CATEGORY USED FOR EACH SITE IN BATCH 4

MAP (1)

	SITE NAME	KEY	SOIL CATEGORY
1.	Arkansas	1	Rock **
2.	Callaway	2	Rock **
3.	Comanche Peak	3	Rock
4.	Cooper	4	Sand-like 1
5.	Crystal River	5	Rock
6.	Duane Arnold	6	Rock **
7.	Fort Calhoun	7	Sand-like 1
8.	Grand Gulf	8	Deep soil
9.	LaCrosse	9	Sand-like 2
10.	Monticello	A	Sand-like 1
11.	Prairie Island	B	Sand-like 2
12.	River Bend	C	Deep soil
13.	South Texas	D	Deep soil
14.	St. Lucie	E	Deep soil
15.	Turkey Point	F	Rock
16.	Waterford	G	Deep soil
17.	Wolf Creek	H	Rock

(1) Key used on Fig. 1.1d.

(**) Have some structures founded in shallow soil.

Figure 1.1a Map showing the location of the Batch 1 sites contained in Vol. II of this report. Map symbols are given in Table 1.1a.

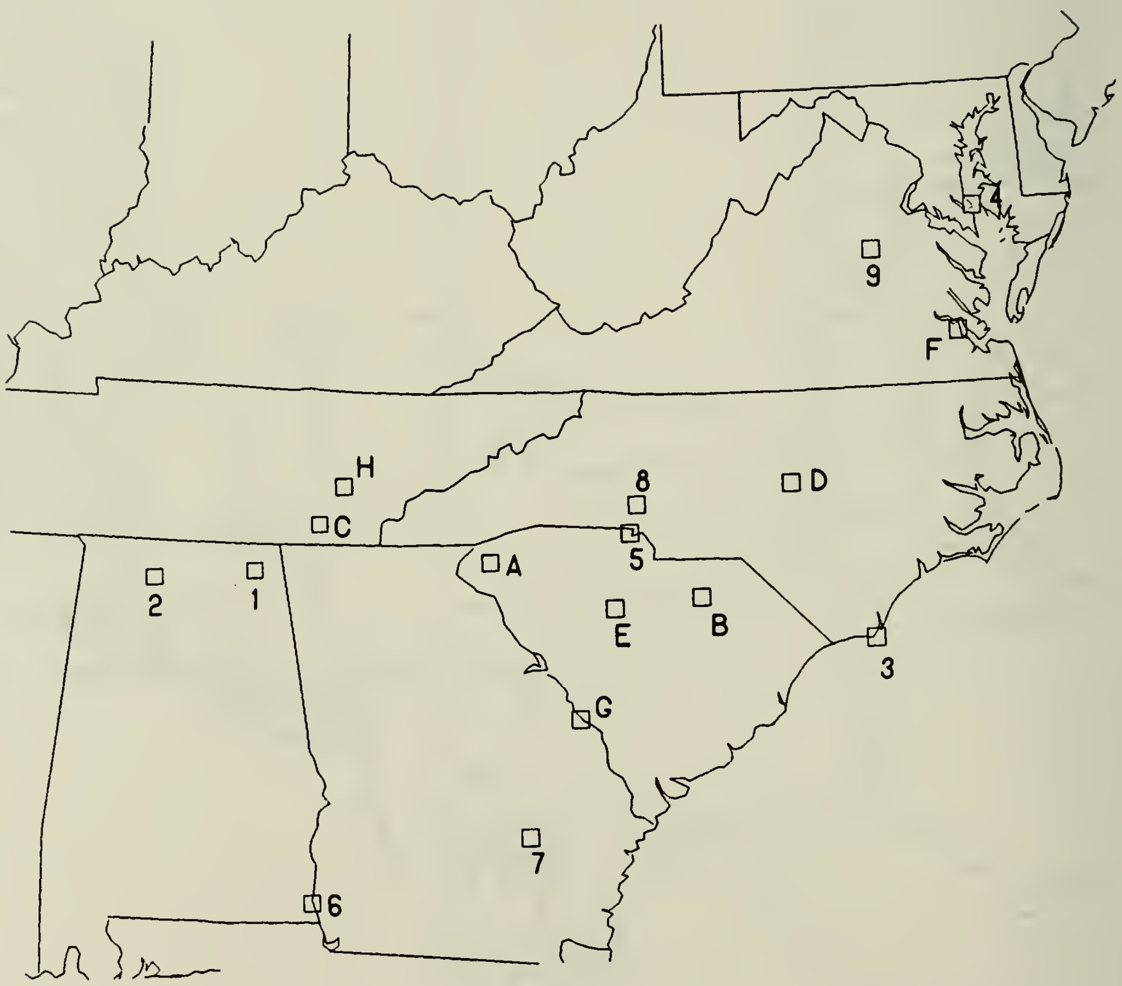


Figure 1.1b Map showing the location of the Batch 2 sites contained in Vol. III of this report. Map symbols are given in Table 1.1b.

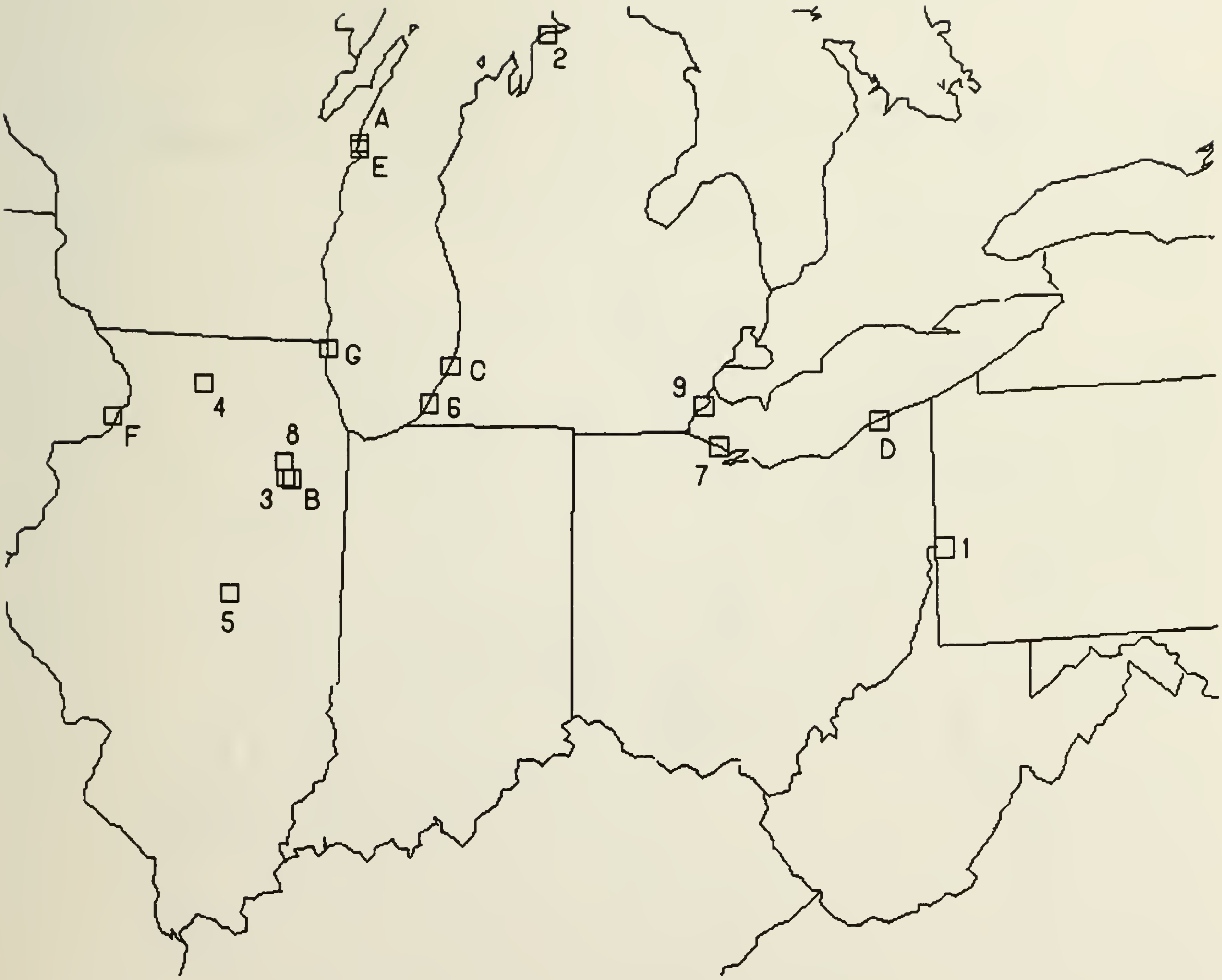


Figure 1.1c Map showing the location of the Batch 3 sites contained in Vol. IV of this report. Map symbols are given in Table 1.1c.

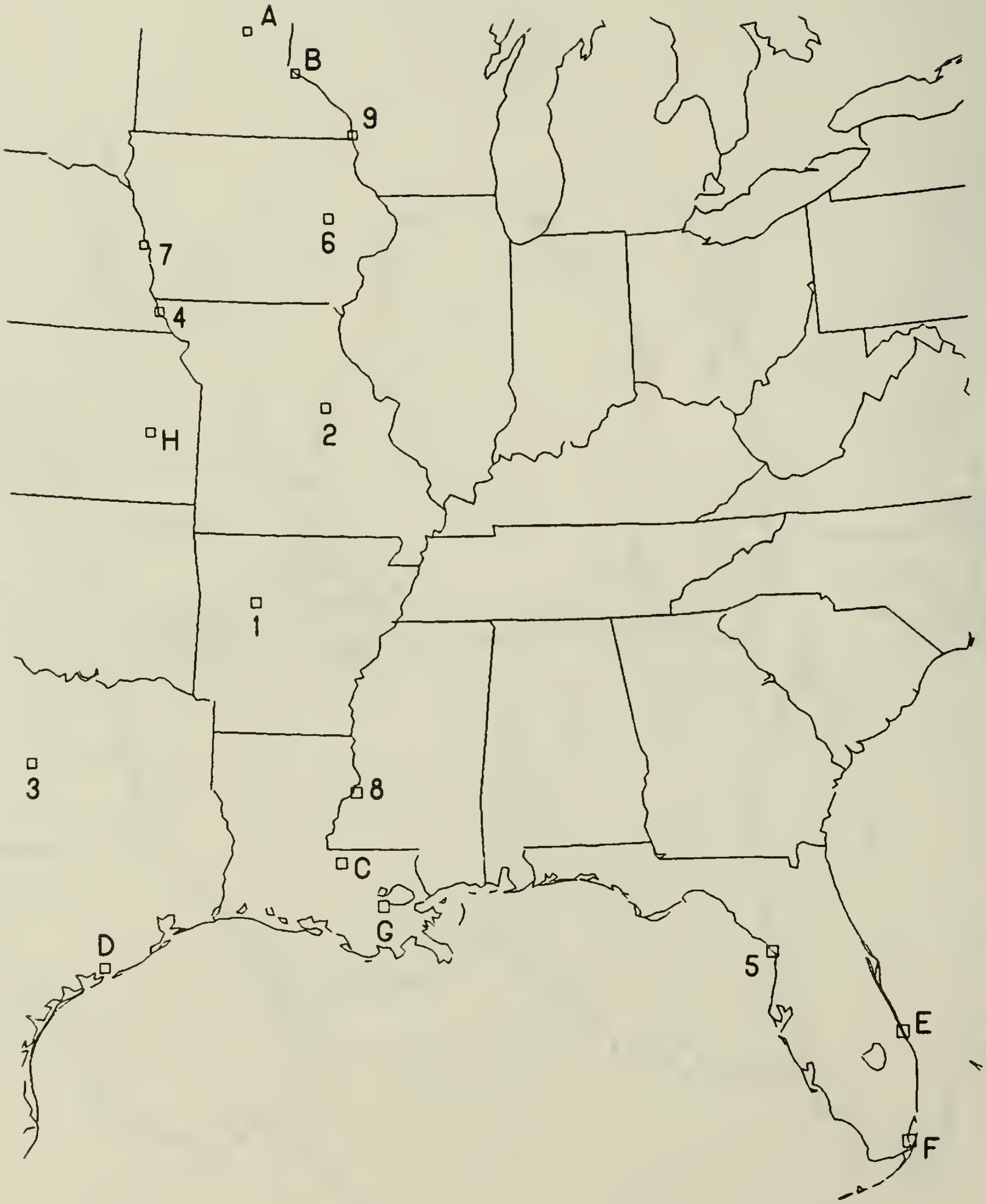


Figure 1.1d Map showing the location of the Batch 4 sites contained in Vol. V of this report. Map symbols are given in Table 1.1d.

Figure 1.2 Map giving the relative location of all the sites included in this study.

2. DISCUSSION OF THE SENSITIVITY OF THE COMPUTED SEISMIC HAZARD TO SEVERAL IMPORTANT ASPECTS OF THE METHODOLOGY USED TO ESTIMATE THE GROUND MOTION

2.1 Background

In Vols. II-V we have identified several important elements of the methodology used to estimate the ground motion that have a significant impact on the results. One of the most significant elements is the method we used to correct the estimated ground motion to account for the site's soil category. A number of examples of the significance of this correction have been pointed out in Vols. II-V. In Section 2.2 we provide a detailed examination of the impact of this element of our methodology on the estimated hazard.

In Vols. II-V we found that differences in the rate at which the ground motion attenuated between the various ground motion models selected by our G-Experts led, in some cases, to relatively large uncertainties in the estimated hazard. In particular the ground motion model selected by G-Expert 5 sometimes lead to hazard estimates significantly higher than from the other ground motion models for a given S-Expert's input. This element is further discussed in Section 2.3.

In Section 2.4 we discuss an element not previously mentioned. Based on a number of studies, e.g., Newmark and Hall (1978), of the relation between PGA and the spectral amplification factors, it is generally assumed that at approximately 33hz the spectral amplification of the PGA is unity. However, if the estimated peak ground acceleration (PGA) hazard given in Vols. II-V is converted to a high frequency spectral value and compared to appropriate spectrum, our PGA values appear to be anomalously low, or conversely our spectra would suggest that at high frequency (25hz and above) we have higher amplification factors than generally assumed based on spectra from WUS earthquakes or design spectra such as NUREG-0098.

2.2 Correction for the Site's Soil Category

In Vol. I Section 3.7 we provide a discussion of the overall approach we used to account for the site's soil category. In Bernreuter et al. (1987) we performed a sensitivity study on site type. However, that study was based on the early input provided by our G-Experts and documented in Bernreuter et al. (1985). The results in this section are significantly different from our previous results primarily because in the previous results a site correction was only applied about half the time. In the updated input four out of the five G-Expert selected our category approach with a weight of 1.0. The other G-Experts selected the simple correction approach with three soil classes: rock, shallow soil and deep soil. In Bernreuter et al. (1985 & 1987) we only allowed for rock and deep soil classes. The net result of the changes in input provided by our G-Experts and our expanded capabilities of allowing for more sub-divisions in the simple correction approach is that the site's soil category is now much more significant than previously found in Bernreuter et al. (1985 & 1987).

As explained in Vol. I Section 3.7 we put all sites in one of the eight soil categories listed in Table 2.2.1. For the four G-Experts who selected our categorized approach explained in Vol. I for each trial of the Monte Carlo simulation a site correction is simulated assuming that the distribution of the correction factor is lognormal with a median plotted in either Fig. 2.2.1 or Fig. 2.2.2. These figures are repeated from Vol. 1 for ease of reference. For G-Expert 5 a constant correction value was always used based on the site's soil category. See Fig. 2.2.3.

To see the significance of the soil category we randomly selected a site and re-ran the analysis eight times with the site's soil category changed each time. In Fig. 2.2.4 we compare the CPHCs between the case when the site's soil category is assumed to be rock and the case when it is assumed to be deep soil. The differences between the median CPHCs for the rock and deep soil categories is relatively small. However, as shown in Fig. 2.2.5 there are much larger differences between the two cases for other estimators. In particular, as can be seen from Fig. 2.2.5, the largest difference is between BEHCs for the two cases. It should be noted that there is a significant variation in the AMHC and BEHC from region to region. Thus the differences between BEHCs for the rock and soil cases and the differences between AMHCs observed cannot be generalized and assumed to occur at other sites. For this reason we primarily focus on the CPHCs and CPUHS.

In Fig. 2.2.6 we compare the CPUHS with a 10,000 year return period for the case when the site's soil category is deep soil to the case when it is rock. We see from Fig. 2.2.6 that the spectral shapes are significantly different. Note, that the difference would appear to be much larger if the spectral velocity scale was linear (as the PGA scale in the preceding figures) rather than logarithmic.

In Fig. 2.2.7 we compare the CPHCs between the cases when the site's soil category is considered as: (1) Till-1, (2) Till-2 and (3) Till-3. Also, shown for reference is the case when the site's soil category is considered to be rock. We see from Fig. 2.2.7 that, as might be expected from examination of the median correction factors in Fig. 2.2.1, there is a significant difference between the hazard curves depending upon the site's soil category. In Fig. 2.2.8 we compare the median 10,000 yr return period CPUHS for the cases when the site's soil category is: (1) Till-1, (2) Till-2, (3) Till-3 and, for reference, (4) rock. Note the change in spectral shape with site category. Once again keep in mind that a logarithmic scale is used. In Fig. 2.2.9 we include both the 15th and 85th percentile 10,000 yr return period CPUHS as well.

In Fig. 2.2.10 we compare the CPHCs for the cases when the site's soil category is considered to be: (1) Sand-1, (2) Sand-2, (3) Sand-3 and, for reference, (4) rock. In Fig. 2.2.11 we compare the median 10,000 yr return period CPUHS for the cases when the site's soil category is considered to be: (1) Sand-1, (2) Sand-2, (3) Sand-3 and, for reference, (4) rock. In Fig. 2.2.12 we include both the 15th and 85th percentile 10,000 yr return period CPUHS for the cases used in Fig. 2.2.11.

We see by comparing Figs. 2.2.7 to 2.2.10 for PGA and Figs. 2.2.8 to 2.2.11 for spectra that at the short period end of the spectrum there is little difference in the hazard due to the site's soil category between the Till-1 or Sand-1 categories and a somewhat larger difference between the Till-2 and Sand-2, and between the Till-3 and Sand-3. In all cases the Till-like hazard is lower. We also see from comparing Fig. 2.2.8 to Fig. 2.2.11 there are some differences in spectral shape between the Till-like categories and the Sand-like categories.

The above comparisons (Figs. 2.2.4 to 12) are for a fixed site. It is natural to ask if the differences are independent of regional seismicity. This can be in part addressed using comparisons made in Vols. II-V. First, it should be noted that Figs. 2.2.4 to 12 were based on the zonation and seismicity for the Limerick site. Thus, to see if the differences between hazard curves due to site's category is regionally independent we need adjacent (or almost adjacent) sites with different site categories located relatively far (at least 200 km) from the Limerick site (see Fig. 1.1a for the location of the Limerick site). The difficult issues in selecting pairs of sites with different soil categories that we can use to address the potential regional variation of the relative change in the hazard at sites due to the site's soil category is to have a criteria for how "close" the sites must be together. We have seen in Vols. II-V that there can be some significant variations between the hazard for relatively nearby sites due to zonation differences. In Table 2.2.2 we list three pairs of sites which, in our opinion, are sufficiently close together and have different soil categories.

In Fig. 2.2.13a we compare the median CPHCs between the Vermont Yankee site (rock) and the Yankee Rowe site (Till-2). In Fig. 2.2.13b we compare the median CPHCs between the Braidwood (rock) and the LaSalle (Till-2) sites and in Fig. 2.2.13c we compare the median CPHCs between the Kewaunee (Till-2) and Point Beach (Till-1) sites. We see by comparing the relative difference between the Till-1 median hazard curves between the rock and Till-2 sites in Figs. 2.2.7, 2.2.13a and 2.2.13b that there is some regional variation. We see that the relative differences between the rock and Till-2 curves is approximately the same between Figs. 2.2.7 and 2.2.13a. However, there is a slightly larger spread between the median rock and Till-2 hazard curves in Fig. 2.2.13b than in Figs. 2.2.7 and 2.2.13a at the high g value end. The spread between the curves is approximately 20% larger, in terms of annual probability of exceedance at PGA levels greater than 1g in Fig. 2.2.13b than in Figs. 2.2.7 and 2.2.13a. At the low g value end there is very little difference in the relative spread between the curves. One reason why the relative effect of site category varies from site to site is because, as discussed in Vols. II-V, the uncertainty is larger at some sites than at others; hence there is a larger variability between the estimated median between two different Monte Carlo simulations. In particular, this variability is relatively large at the Braidwood site. Reference should be made to Fig. 3.1.1 in Vol. IV. The regional variation in the effect of site correction on the hazard is examined in some detail in Vol. VIII. It shows that there can be a large variation between the correction for site type and in particular either the AMHC or the 85th percentile CPHC. This is

illustrated in Fig. 2.2.14 where we compare the CPHC for the Browns Ferry site for the case when it is ran as a deep soil site to the case when it is ran as a rock site. We see that there is about the same variation between the median CPHCs for the two cases as shown in Fig. 2.2.4, however, there is a much larger difference between the 85th percentile CPHCs for the two cases in Fig. 2.2.14 than in Fig. 2.2.4. The same difference is observed between the AMHCs for the two cases for the two sites as can be seen by comparing Figs. 2.2.5 to 2.2.15.

It should be noted based on the preceding comparisons that although there appears to be little regional variation in the correction for site type for the median hazard curve there is, as discussed in Section 3, considerable regional variation in the resultant spectral shape for a given soil category.

If the median correction factors given in Figs. 2.2.1 and 2.2.2 are compared to the comparisons made between median CPHC for PGA and median CPUHS, one finds for the sites studied that the simulated median hazard curve or UHS for a given site category is within approximately 10-20 percent of the rock case multiplied (parallel to the PGA axis) by the appropriate median correction factor. See Section 3 for details. Generally the simulated curve is lower than the curve obtained by the simple correction procedure outlined above. For sites with large uncertainties there can be larger variation, however, this is due to the variation between successive Monte Carlo runs. At higher probability of exceedances the difference between simulated correction and a simple ratio correction is larger than at low probabilities of exceedance. It is, however, difficult to estimate the impact of soil variation on either the 85th percentile CPHCs or AMHCs.

In Volume VIII we provide calculations for the seismic hazard at the current nuclear power plant sites which have critical structures founded on several soil categories. In Volume VIII it is concluded that, in general, it is not correct to account for site effects simply by scaling the final hazard curve. There are cases where it would be correct, but at the present time there is no simple way of knowing which are these cases without performing a full analysis.

TABLE 2.2.1

DEFINITION OF THE EIGHT SITE CATEGORIES

		CATEGORY	DEPTH
Generic Rock			
(1)		Rock	N/A
Sand Like			
(2)	Sand 1	S1	25 to 80 ft.
(3)	Sand 2	S2	80 to 180 ft.
(4)	Sand 3	S3	180 to 300 ft.
Till-Like			
(5)	Till 1	T1	25 to 80 ft.
(6)	Till 2	T2	80 to 180 ft.
(7)	Till 3	T3	180 to 300 ft.
Deep Soil			
(8)		Deep Soil	N/A

TABLE 2.2.2
NEARBY SITES IN DIFFERENT SOIL CATEGORIES

Site Pair	Soil Category	Location Map Fig. Number
Vermont Yankee Yankee Rowe North East U.S.	Rock Till-2	1.1a 1.1a
Braidwood LaSalle North Central U.S.	Rock Till-2	1.1c 1.1c
Kewaunee Point Beach North Central U.S.	Till-2 Till-1	1.1c 1.1c

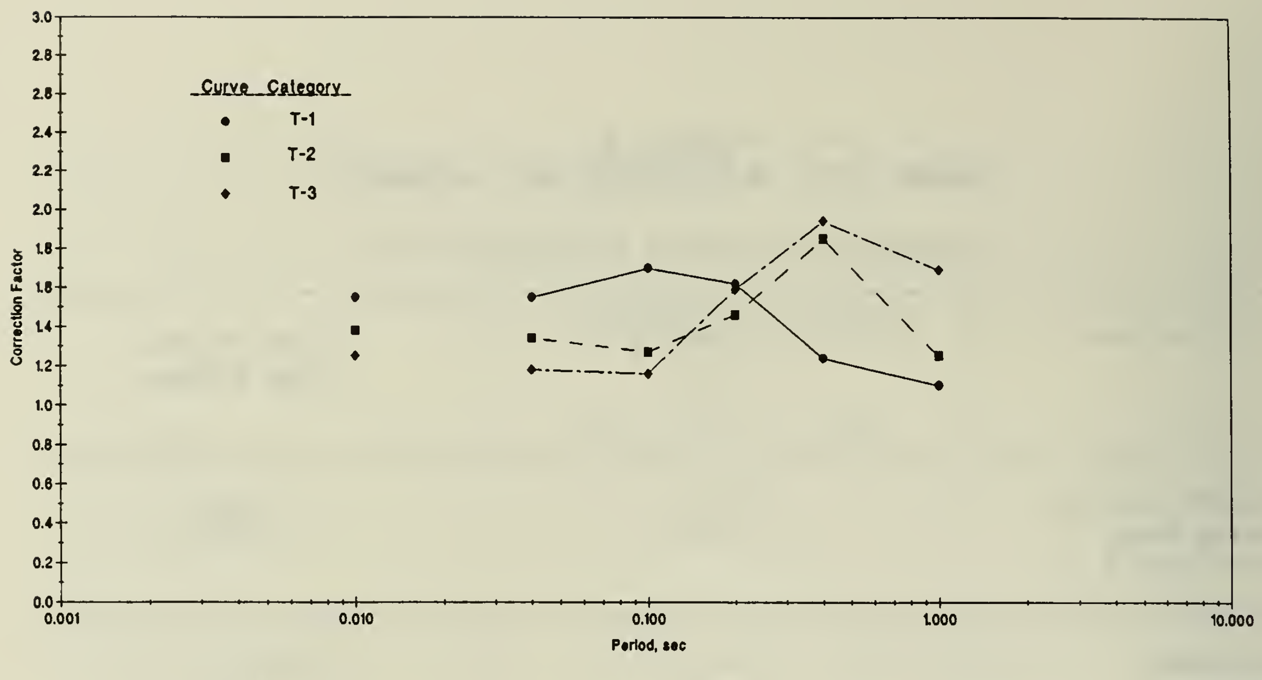


Figure 2.2.1 Smoothed median correction factors for the Till-like catagories listed in Table 2.2.1 relative to rock. The PGA correction factors are plotted at 0.01s.

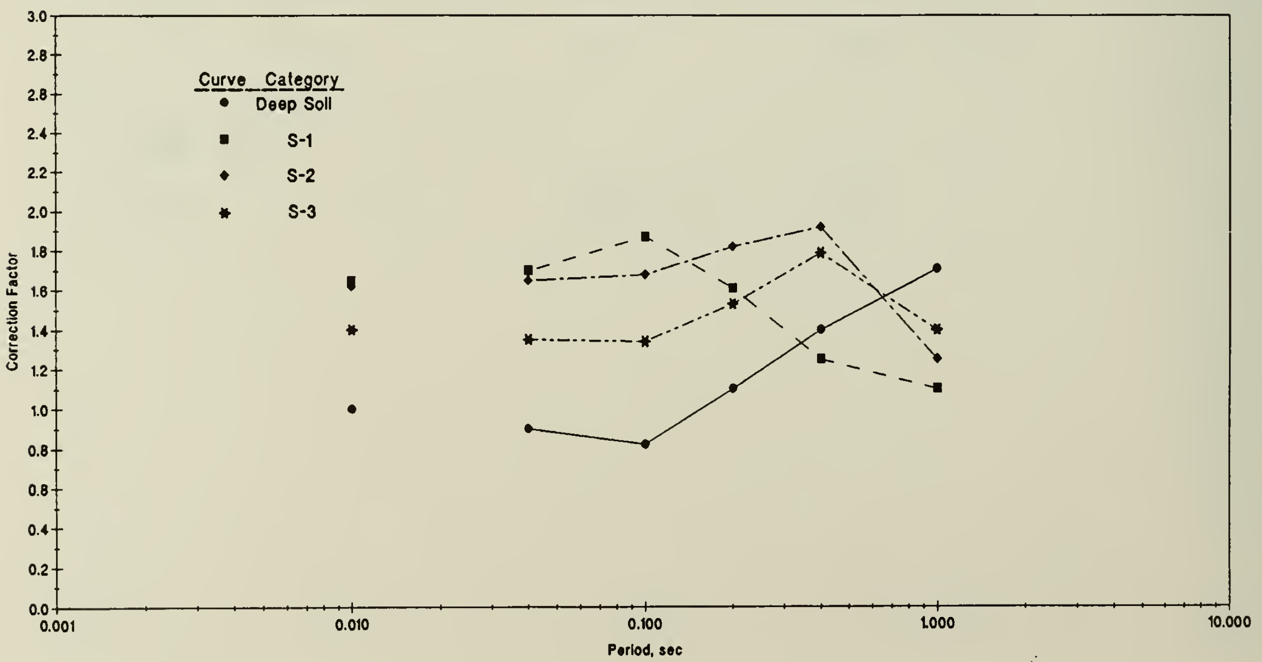


Figure 2.2.2 Smoothed median correction factors for the Sand-like categories listed in Table 2.2.1 relative to rock. The PGA correction factors are plotted at 0.01s.

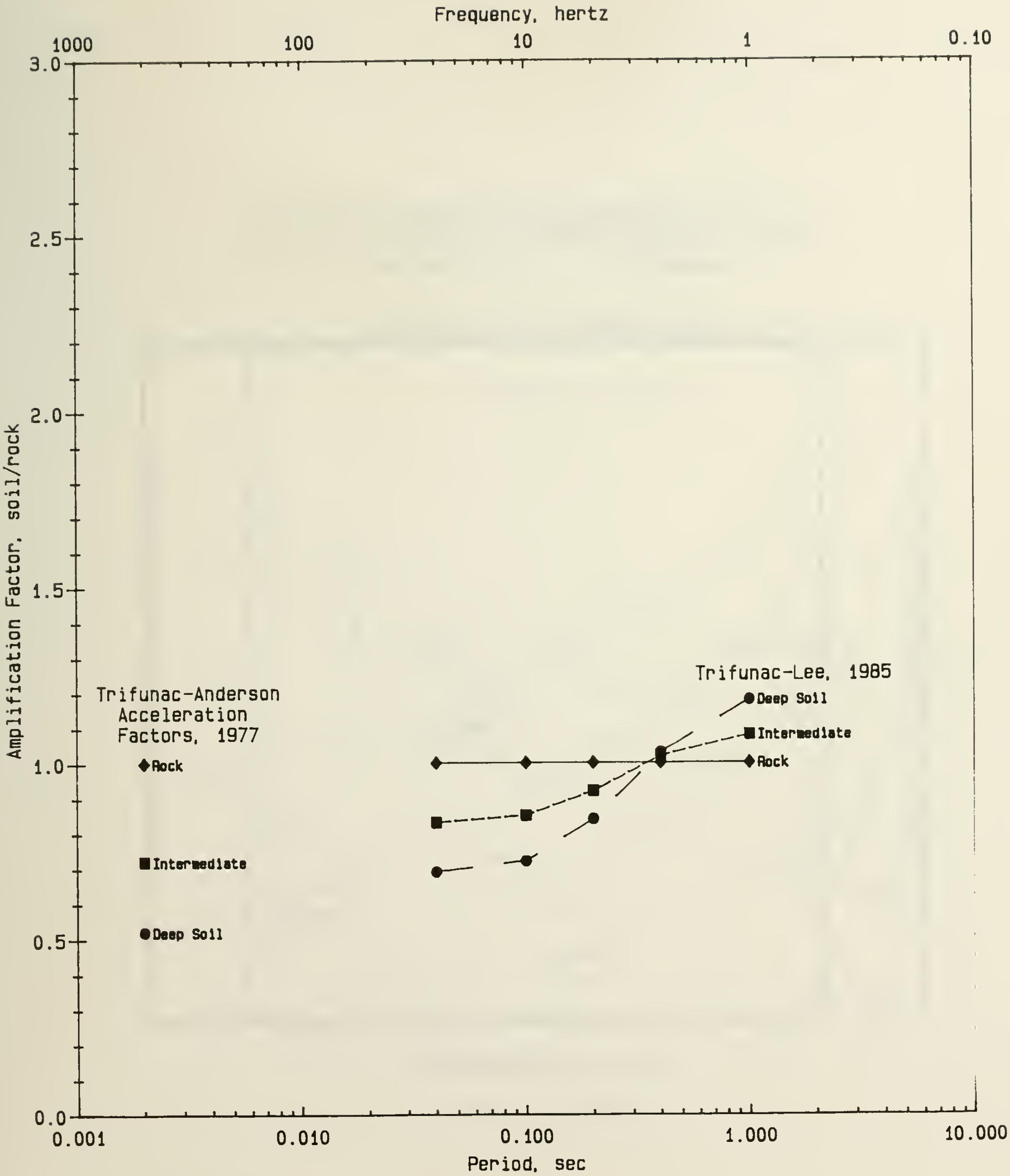


Figure 2.2.3 Simple correction factors selected by G-Expert 5.

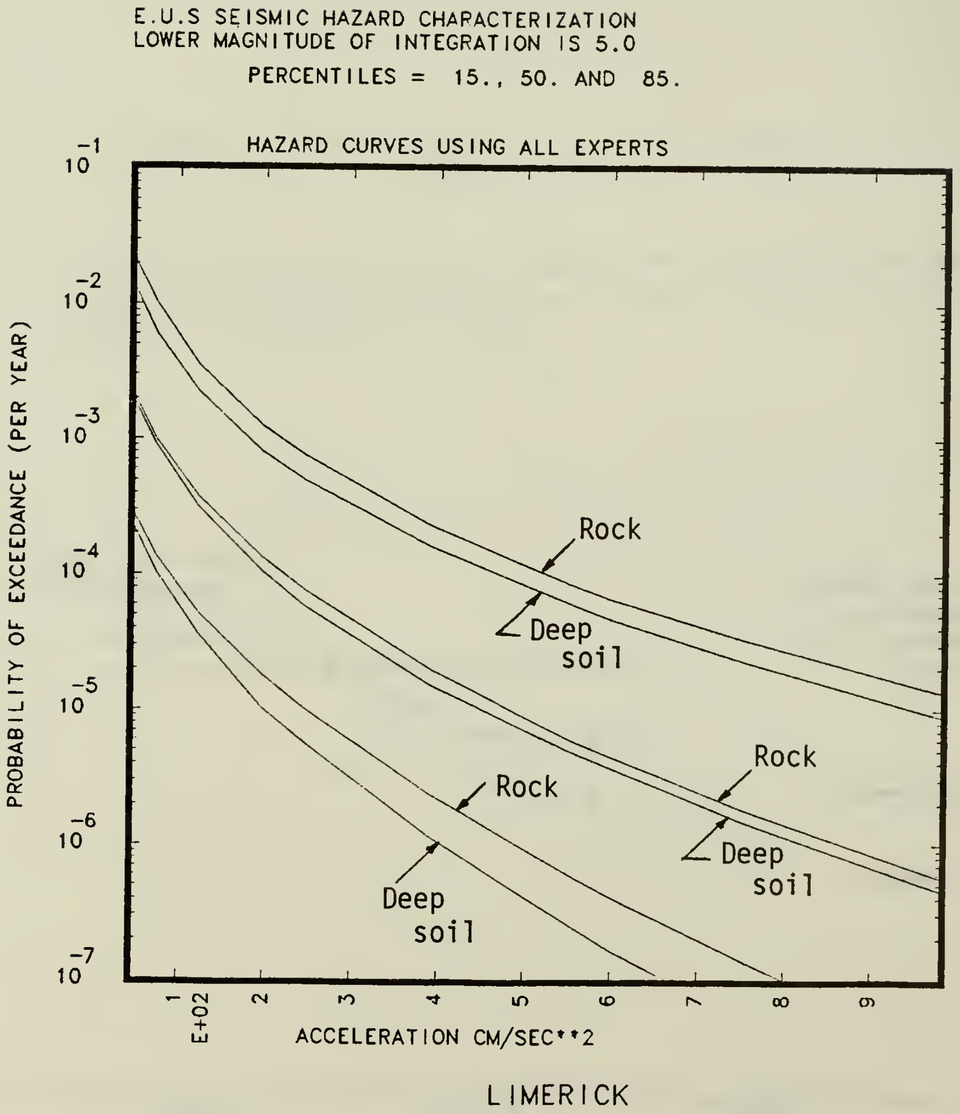


Figure 2.2.4 Comparison between the CPHCs for the case when the Limerick site's soil category is rock and the case when it is considered to be deep soil.

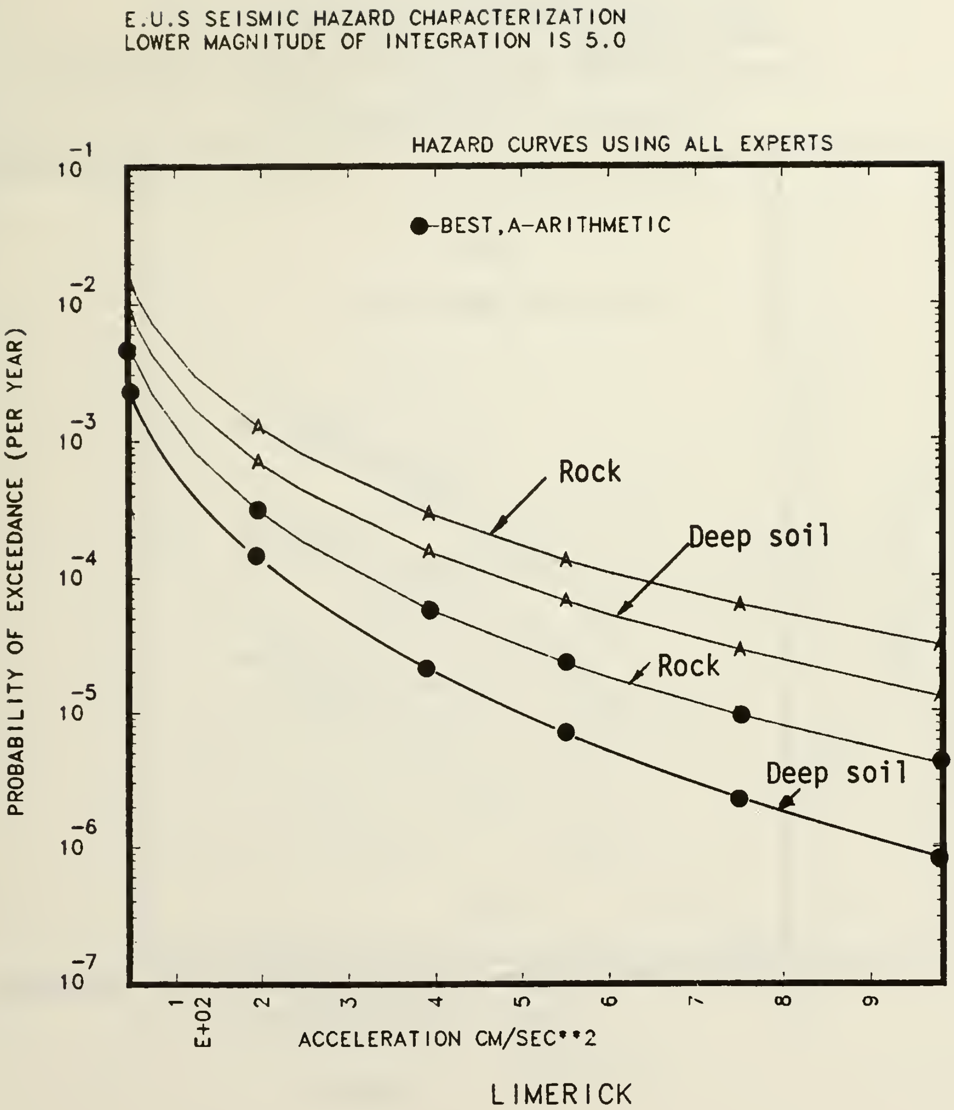


Figure 2.2.5 Comparison between the AMHCs and the BEHCs for the case when the Limerick site's soil category is rock and the case when it is deep soil.

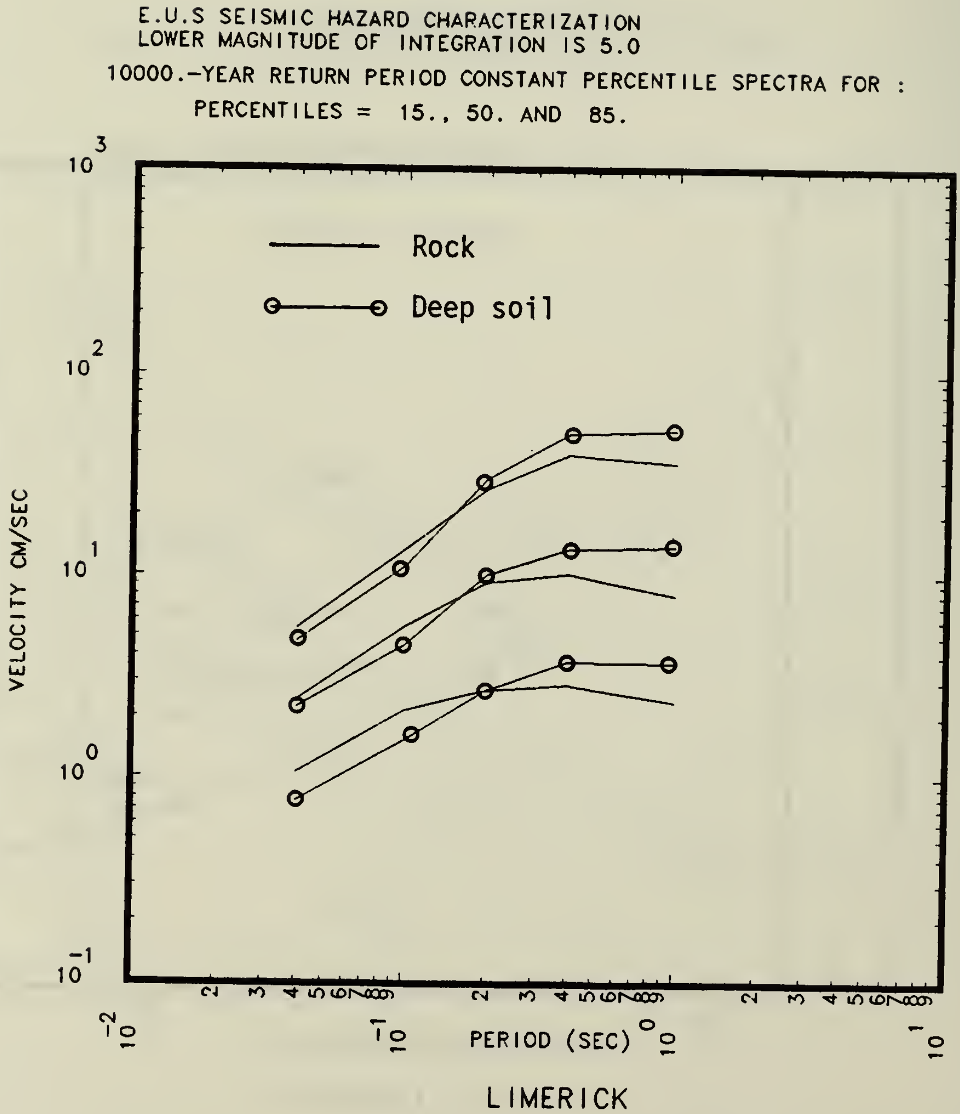


Figure 2.2.6 Comparison between the CPUHS with a 10,000 year return period for the case when the Limerick site's soil category is rock and the case when it is deep soil.

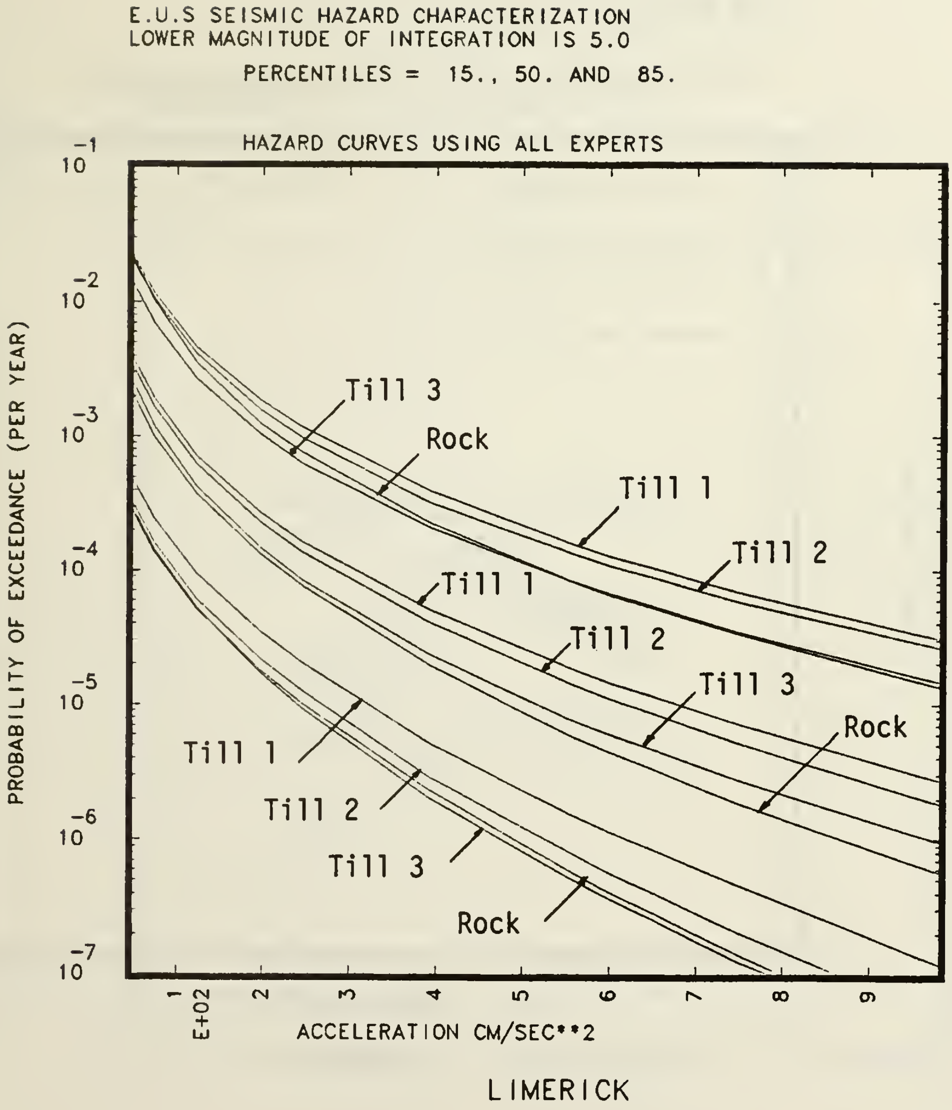


Figure 2.2.7 Comparison between the CPHCs for the case when the Limerick site's soil category is considered to be: Till-1, Till-2 and Till-3. For comparison the rock case is also plotted.

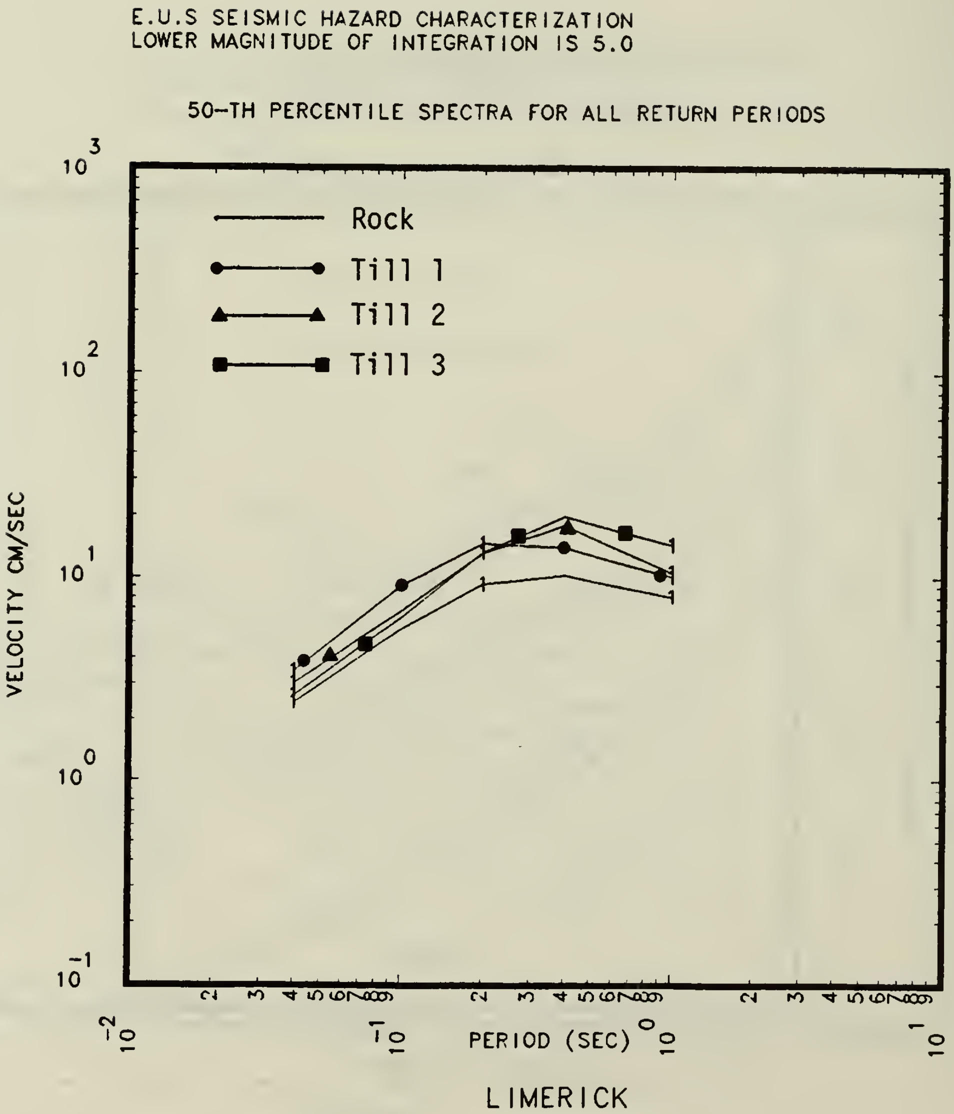


Figure 2.2.8 Comparison between the median 10,000 year reutrn period CPUHS for the case when the Limericks site soil category is considered to be: Till-1, Till-2 and Till-3. For comparison the rock case is also plotted.

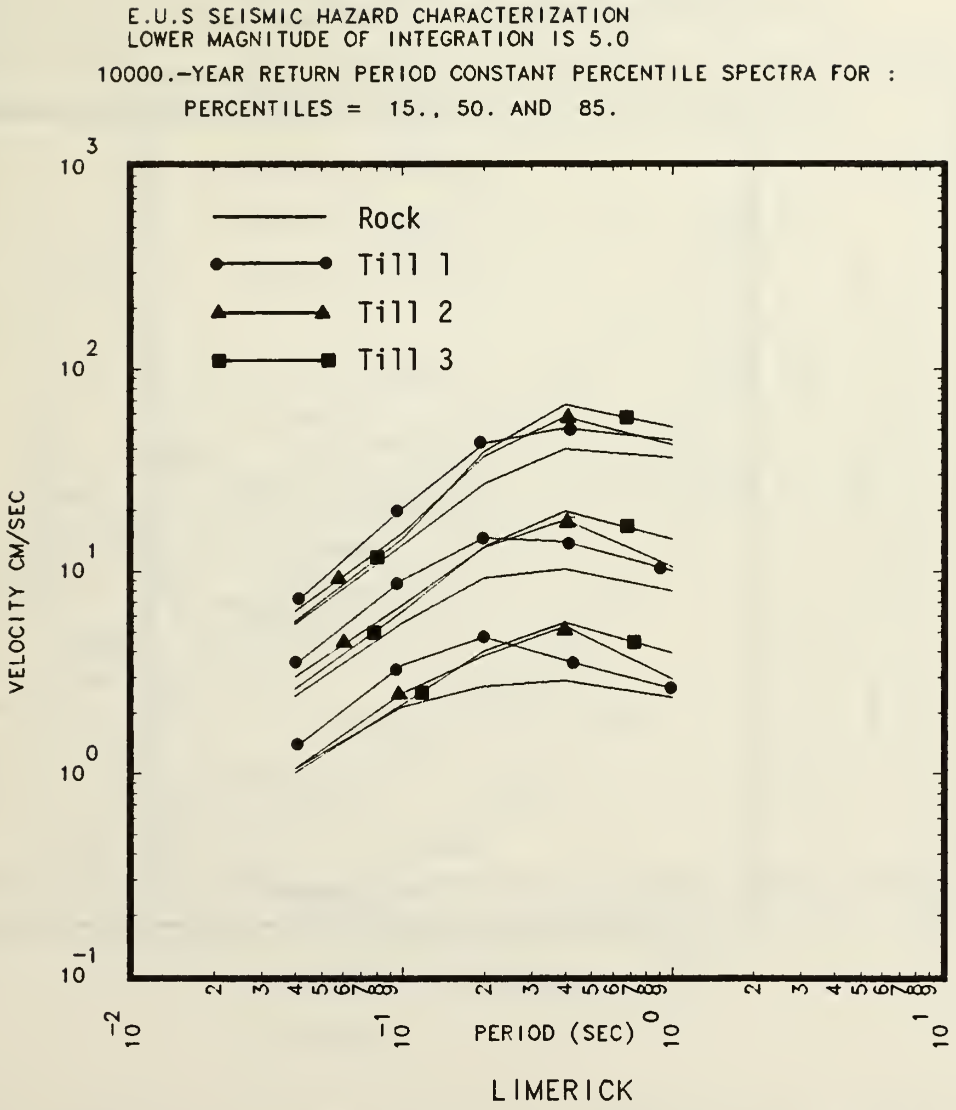


Figure 2.2.9 Same as Fig. 2.2.8 except the 15th and 85th percentile CPUHS are also plotted.

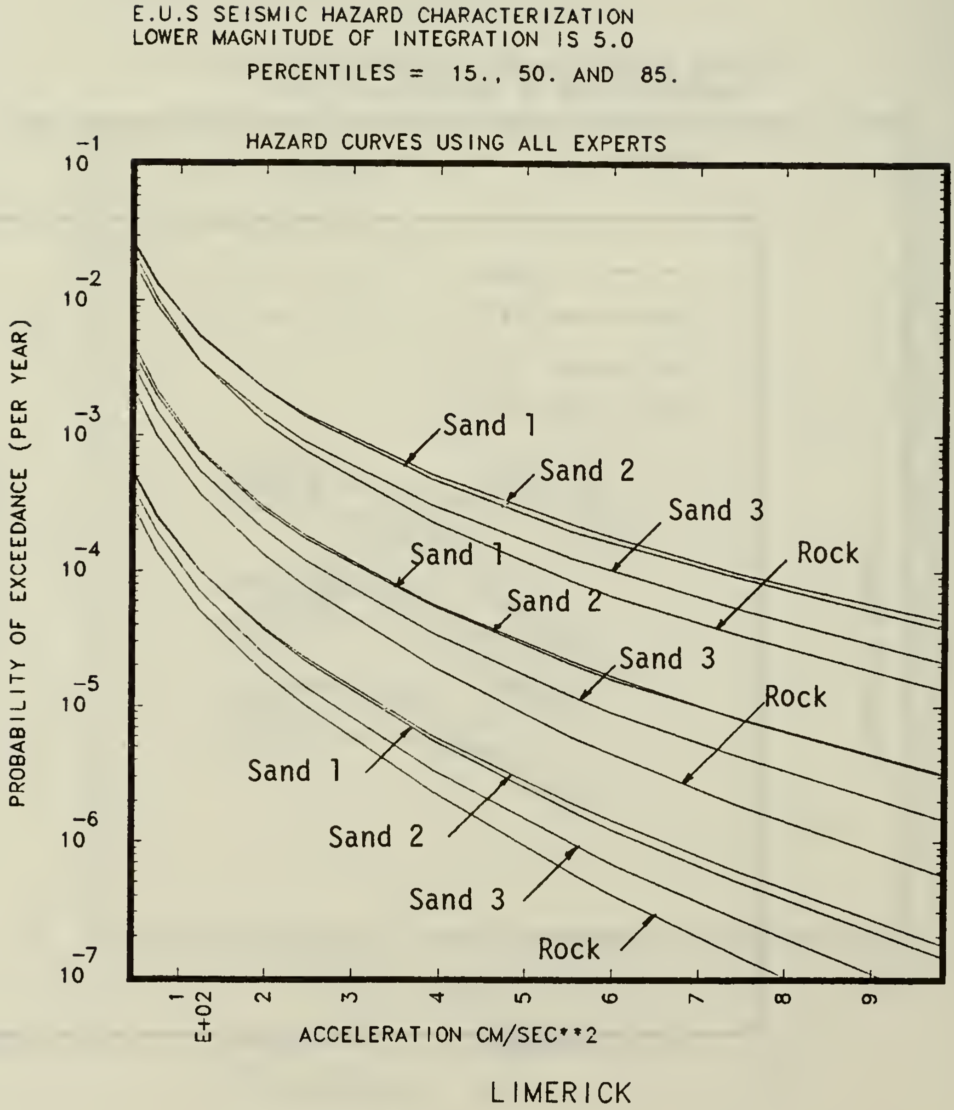


Figure 2.2.10 Comparison between the CPHCs for the cases when the Limerick site's soil category is considered to be: Sand-1, Sand-2 and Sand-3. For comparison the rock case is also plotted.

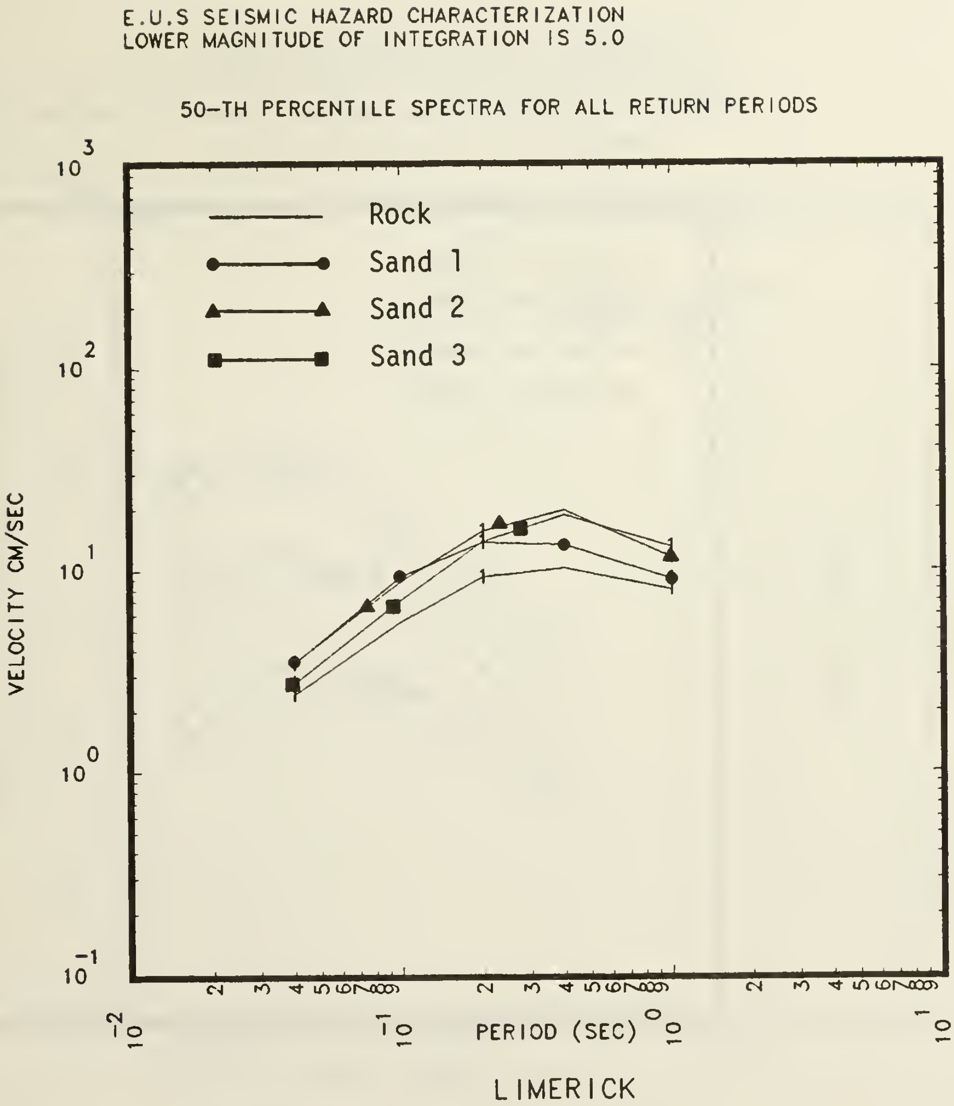


Figure 2.2.11 Comparison between the median 10,000 year return period CPUHS for the cases when the Limerick site's soil category is considered to be: Sand-1, Sand-2 and Sand-3. For comparison, the rock case is also plotted.

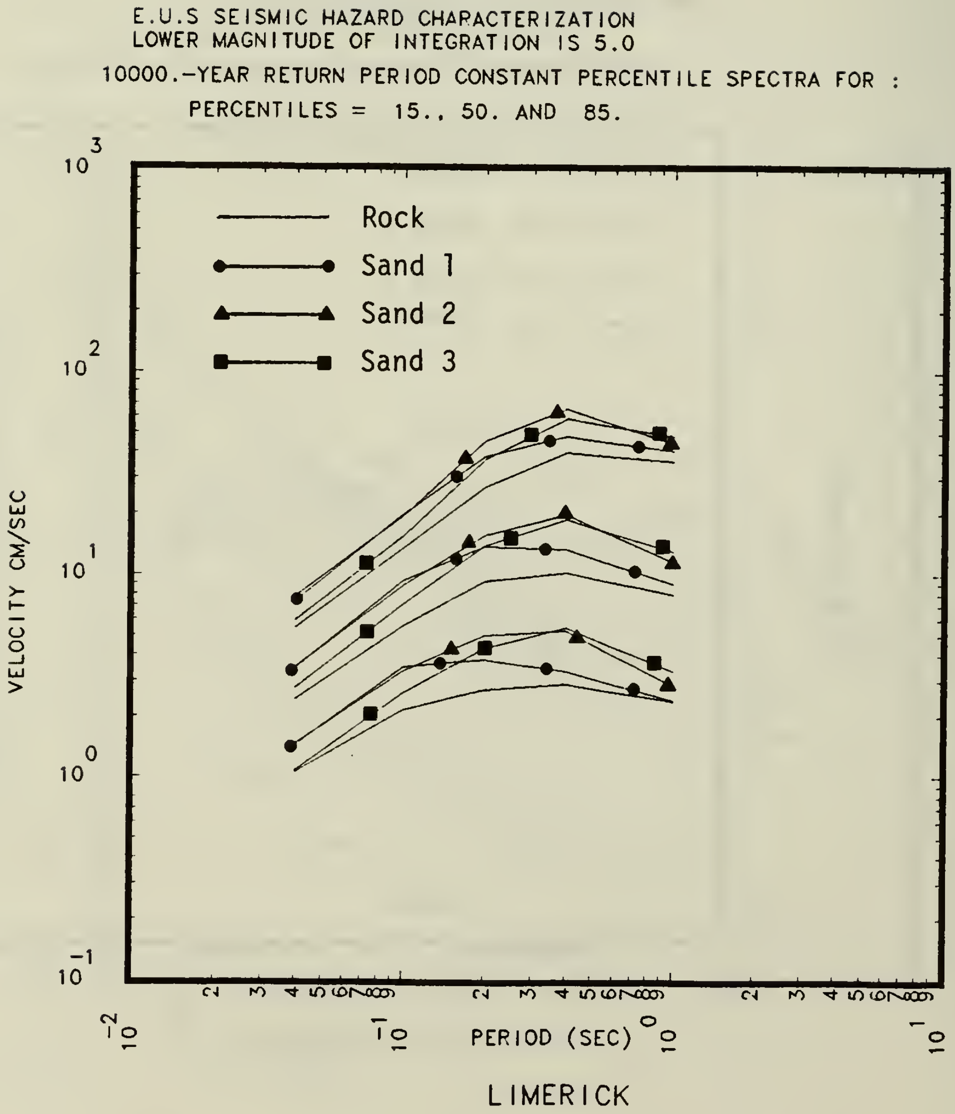


Figure 2.2.12 Same as Fig. 2.2.11 except the 15th and 85th percentile CPUHs are also plotted.

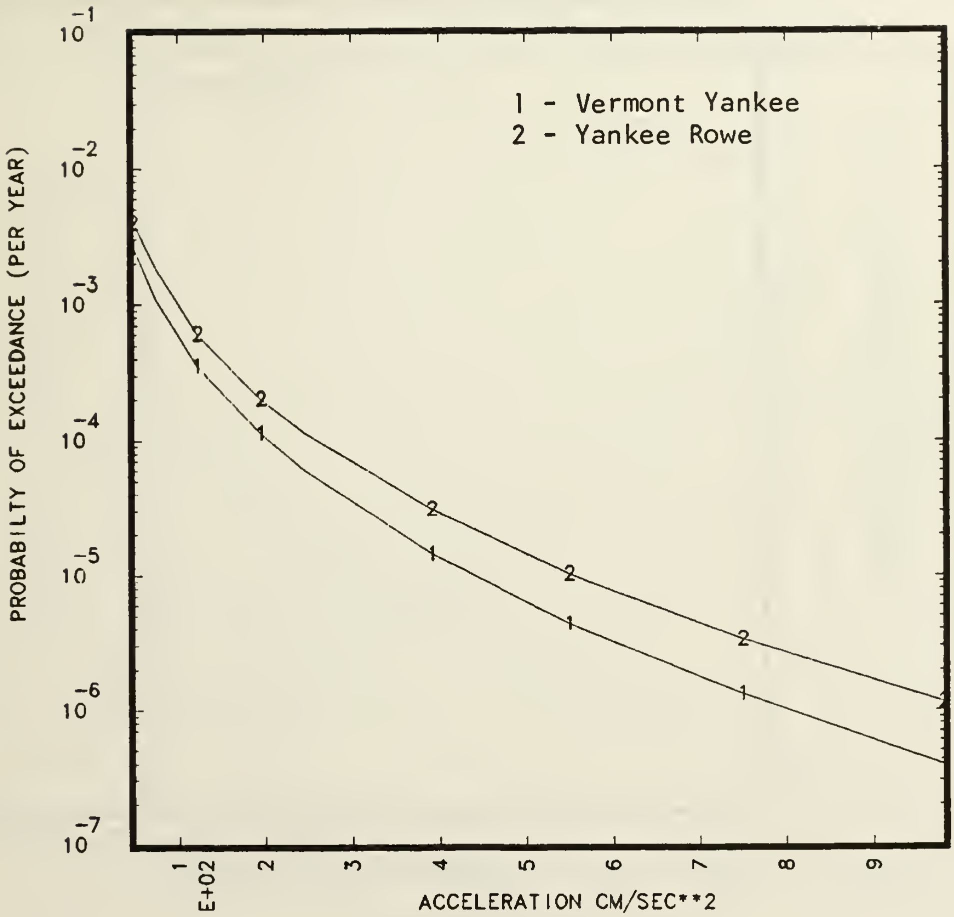


Figure 2.2.13a Comparison of the median CPHCs between the Vermont Yankee site (rock) and the nearby Yankee Rowe site (Till-2).

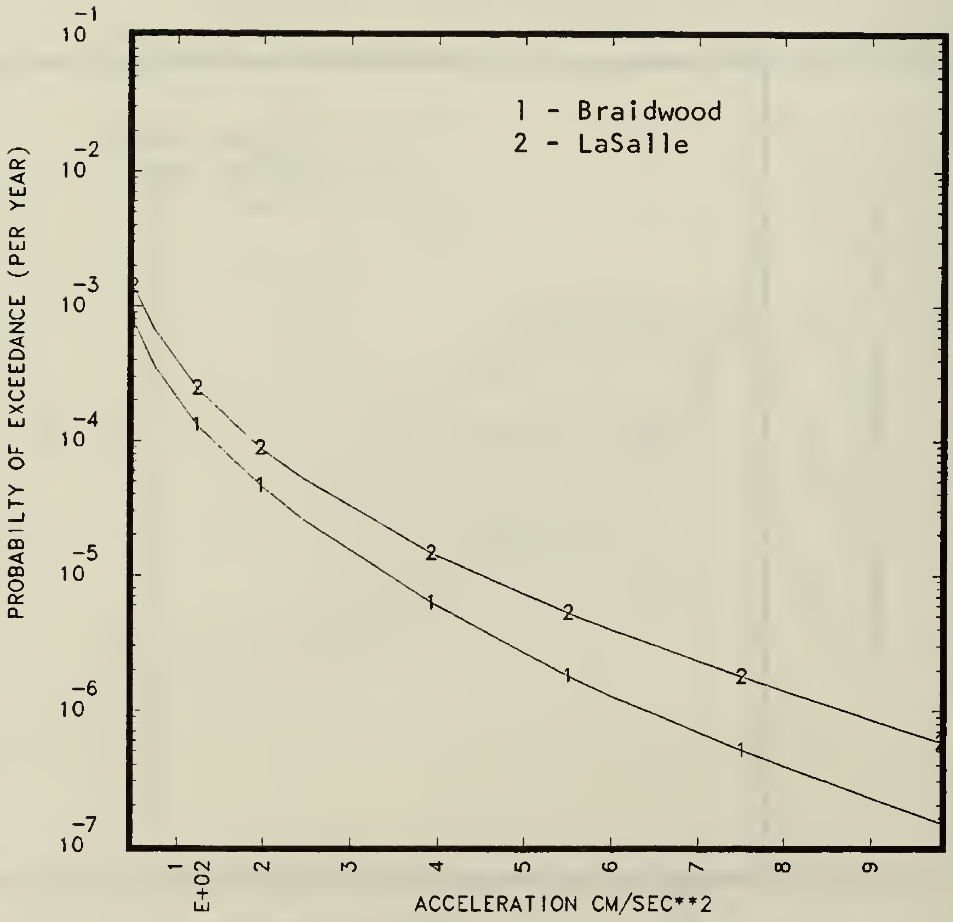


Figure 2.2.13b Comparison of the Median CPHCs between the Braidwood site (rock) and the nearby LaSalle site (Till-2).

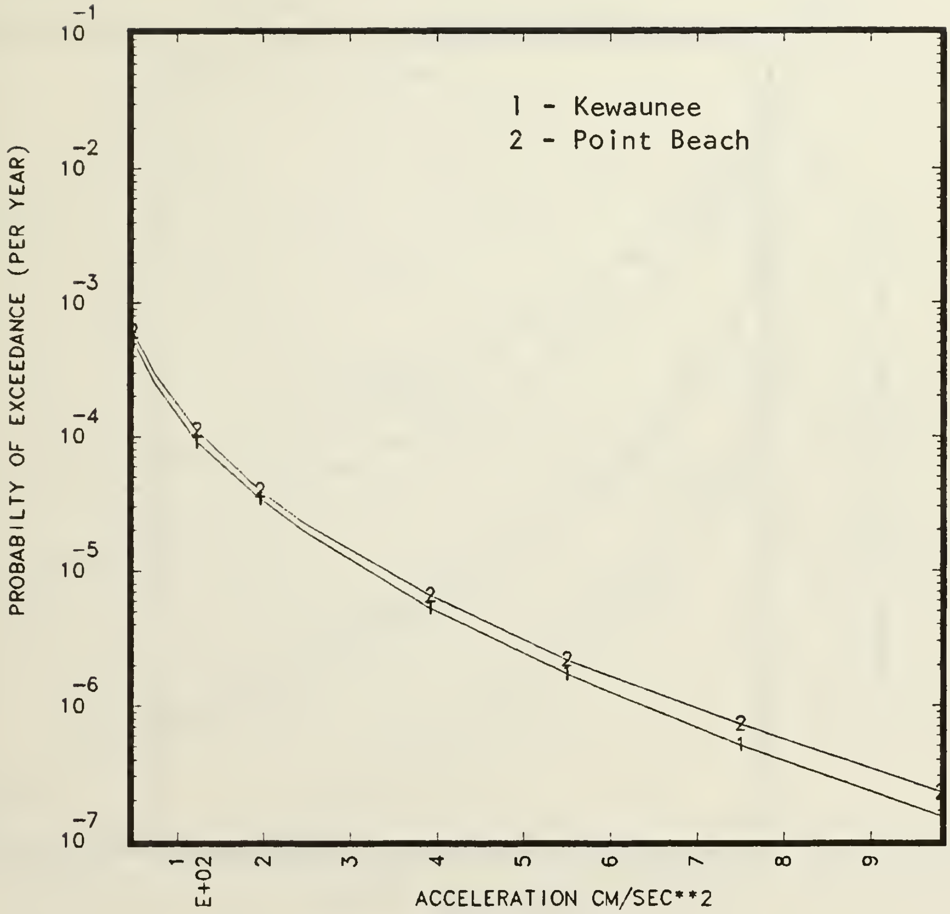


Figure 2.2.13c Comparison between the Median CPHCs for the Kewaunee site (Till-2) and the Point Beach site (Till-1).

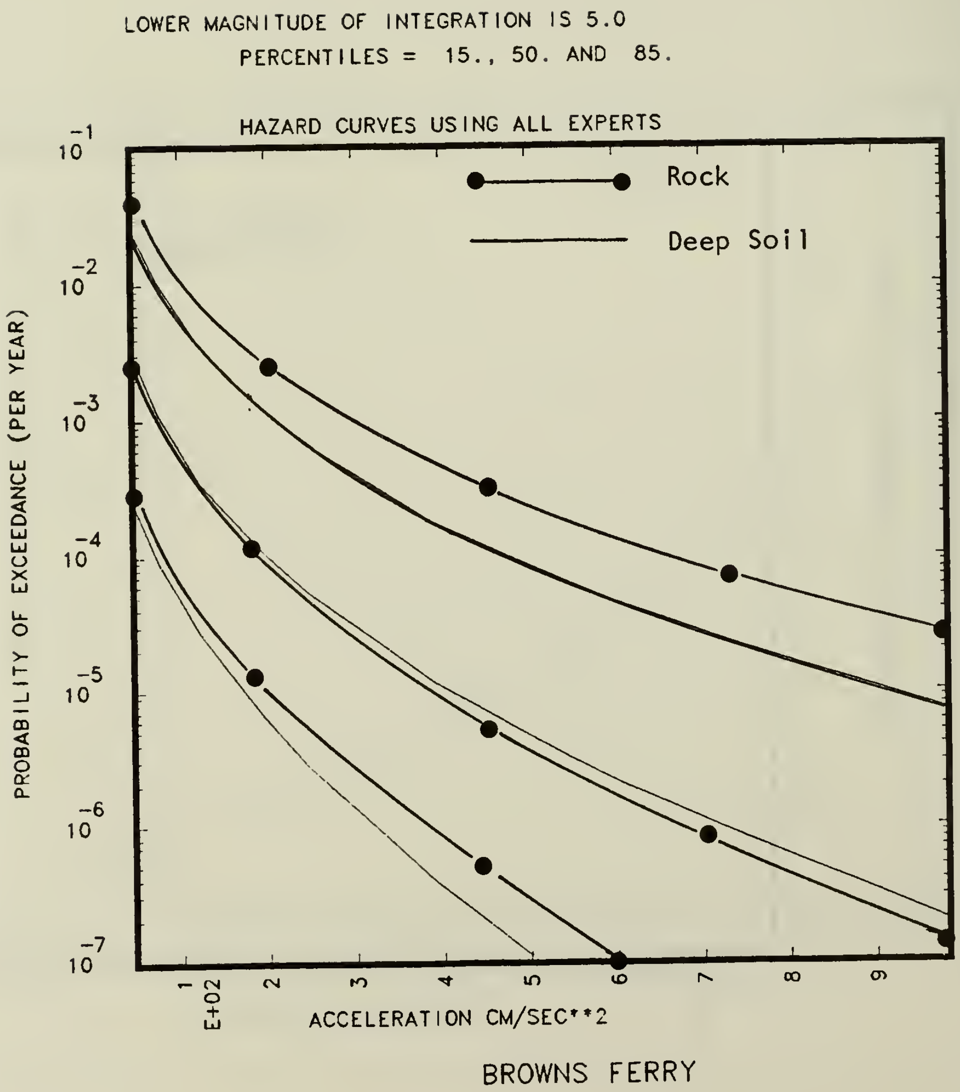
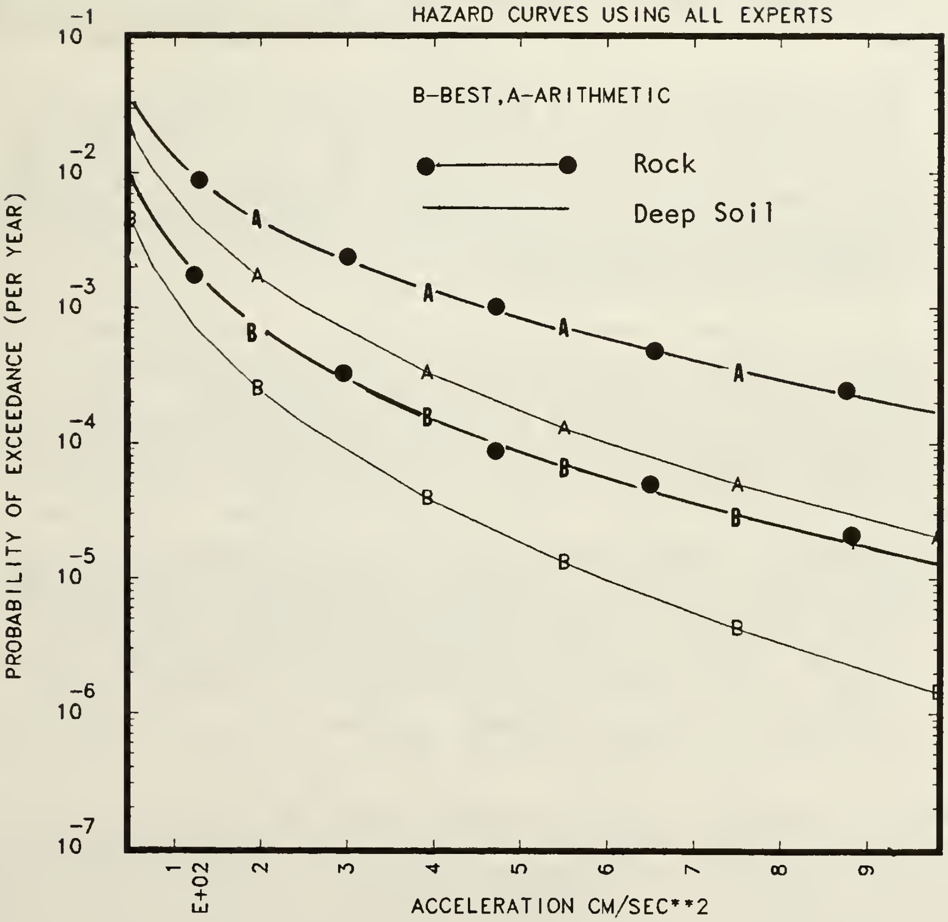


Figure 2.2.14 Comparison between the CPHCs for case when the Browns Ferry site is rock and the case when it is treated as a deep soil site.

LOWER MAGNITUDE OF INTEGRATION IS 5.0



BROWNS FERRY

Figure 2.2.15 Comparison between the AMHCs and BEHCs for the Browns Ferry site ran as a rock site and as a deep soil site.

2.3 Sensitivity to G-Expert 5's Model

In Vols. II-V we have noted (e.g., Vol. II Sec. 2.1) that at rock sites G-Expert 5's BEHC per S-Expert is significantly higher than the other G-Experts' BEHCs per S-Expert. See Fig. 2.3.1a for a typical example. In some instances, particularly for the case when a site is several hundred kilometers of a zone such as the New Madrid seismic zone and located for a given S-Expert in a zone of very low seismic activity (i.e., where the dominant contribution comes from a distant zone more than 150 to 200 km away, with high magnitude cutoff), there can be a much larger difference between G-Expert 5's BEHC per S-Expert and the other G-Experts' BEHCs for the same S-Expert as shown in Fig. 2.3.1b.

Although we have discussed this issue at some length in each of Vols. II-V, it is sufficiently important to warrant additional discussion. As discussed in Vols. II-V the main reasons for the large spread between G-Expert 5's BEHC per S-Expert and the other G-Experts' BEHCS per the same S-Expert are:

(1) As discussed in Vol. 1 Section 3.5, the site correction factor selected by G-Expert 5 at rock sites multiplies the PGA by approximately a factor of 2 relative to the other BE GM models for the same distance and magnitude. A factor of 2 in PGA results in approximately a factor of 8-10 (or even more at low PGA values) in probability of exceedance.

(2) It can be seen from Fig. 3.4 in Vol. 1 that G-Expert 5's BE PGA (GM model G16-A3) has significantly lower attenuation than the other models particularly at the larger magnitudes. This coupled with the site correction factor for rock increases the contribution from distant zones which have larger earthquakes and a relatively high rate of activity.

(3) G-Expert 5 sets the BE value for the random uncertainty (standard deviation on the natural log of the PGA) to 0.7 compared to the range of values (0.35 - 0.55) selected by the other G-Experts. Relative to results obtained with a value of 0.55, this larger uncertainty (0.7) leads to an increase in the G-Expert 5's BEHC by about a factor of 2 in probability of exceedance at lower (0.2g) g-values to over a factor of 3 at high g-values (0.9g).

In summary we typically expect at rock sites that BEHC for G-Expert 5 for any S-Expert will be about a factor of 10-20 higher in probability of exceedance relative to the other BE GM models (factors (1) and (3) noted above) as illustrated in Fig. 2.3.1a. When the seismicity of the zones around the site are so low that there is very little contribution to the seismic hazard at a given site for a given S-Expert's input, then the low attenuation of G-Expert 5's BE model, factor (2) becomes very important leading to the results shown in Fig. 2.3.1b.

Based on Figs. 2.3.1a and b we would expect that deleting G-Expert 5's GM model would have a significant impact on the hazard computed at many sites. To help understand the site to site variation observed in the sensitivity of the results to the inclusion/non-inclusion of G-Expert's 5 model, it is useful to note that the site can be placed into one of four categories:

(1) Rock sites generally located in a region of low seismic activity (at least for some S-Experts) and located 200-600 km from a zone of very high activity with high upper magnitude cut off. Many sites fall into this category, see Vols. II-V.

(2) Rock sites where the hazard is primarily from nearby zones. In particular see Vols. II and III.

(3) Similar to (1) but a soil site.

(4) Similar to (2) but a soil site.

In Fig. 2.3.2a we illustrate a typical example for a category (1) site such as the Browns Ferry site where we reran the analysis only using G-Experts 1-4 GM models. We see from Fig. 2.3.2a that the 85th percentile CPHC is very sensitive to inclusion/non-inclusion of G-Expert 5's GM model. The median is less sensitive to the inclusion/non-inclusion of G-Expert 5's GM model and the 15th percentile is even less sensitivity than the median. The AMHC is extremely sensitive to the inclusion/non-inclusion of G-Expert 5's GM model as can be seen from Fig. 2.3.2b.

The sensitivity of the computed hazard to inclusion/non-inclusion of G-Expert 5's GM model for sites that fall into category (2) is less than for category (1) sites as is illustrated in Fig. 2.3.3. The Limerick site used for the comparison is a typical rock site where the hazard is primarily from zones near the site. We see by comparing Fig. 2.3.2a to Fig. 2.3.3 that at the Limerick site the 85th percentile is much less sensitive to the G-Expert 5's GM model than at the Browns Ferry site. However, there is only a relatively small change in the sensitivity of the median and 15th percentile CPHCs to the inclusion/non-inclusion of G-Expert 5's GM model between the Browns Ferry site (category (1) type sites) and the Limerick (category (2) type sites).

Unlike the differences in the sensitivity of the computed hazard to the inclusion/non-inclusion of G-Expert 5's model between category (1) and (2) type of sites, there is very little difference in the sensitivity of the CPHCs to the inclusion/non-inclusion of G-Expert 5's GM model between category (3) and (4) type of sites, as can be seen by comparing Figs. 2.3.4 to 2.3.5. In Fig. 2.3.4 the River Bend site is a typical example of a category (3) site and the Salem site used for Fig. 2.3.5 is a typical example of a category (4) site. We see by comparing Fig. 2.3.4 to Fig. 2.3.5 that there is little difference between the computed 85th percentile CPHC between including or not including G-Expert 5's GM model. The sensitivity of the median CPHC to G-expert 5's GM model is about the same for category (3) and (4) type of sites and only slightly less than for category (2) type of sites.

One of the main reasons for the impact of G-Expert 5's GM model on the median for all cases is reason (2) (high value of the random uncertainty) in the list of three reasons given earlier for why G-Expert 5's model tended to be higher for many S-Experts input as compared to the other G-Experts' models.

The sensitivity of the CPUHS to G-Expert 5's GM model is approximately the same as illustrated for PGA, however, it "looks" different because in the comparisons between the estimated CPHCs the parameter of interest was the probability of exceedance whereas for the CPUHS, comparisons are made relative to actual spectral velocity. This is illustrated in Fig. 2.3.6 where we compare the 10,000 year return period CPUHS for the Browns Ferry site between the case when G-Expert 5's GM model is included and the case when it is not included.

One important aspect of this comparison, in Fig. 2.3.6, is that the spectral shape is not changed by including or not including G-Expert 5's ground motion model. This point is repeated in Section 3.3 in the regional spectral comparisons.

Because of the significance of the model selected by G-Expert 5 it might be worthwhile to review some of the good and bad aspects of the model relative to other models selected by the G-Experts. These comments are distilled from points made in our Ground Motion Questionnaires (i.e., questionnaires Q4, Q6 and Q10 which are given in Vol. 7). First, it should be noted that the model selected by G-Expert 5 is a data-based model. The model is made up by selecting a smoothed attenuation of intensity as a function of epicentral intensity and distance. G-Expert 5 selected the attenuation model developed by Gupta and Nuttli (1976) and modified as suggested in Q4 by a reduction in 0.5 intensity units to account for the fact that Gupta and Nuttli's worked with isoseismals rather than the median distances. The selected attenuation model was labeled model A3 in Q10. This attenuation of intensity model was based on several larger EUS earthquakes including the 1811-12 New Madrid series. No estimate of the "error of the fit of the model is given by Gupta and Nuttli (1976). However, typical fits of the attenuation of sensitivity generally yield a random error of over one intensity unit.

In order to be used in our analysis, it is necessary to convert site intensity to a ground motion estimate. G-Expert 5 agreed that all the methods of doing this are flawed, however, the "best" approach, given the data available and the known differences between the EUS and WUS attenuation of ground motion, is to convert I_s to ground motion directly. There are many possible ways of doing this conversion as indicated in Q4 and Q10 of Vol. 7. In all cases one lacks data to account for the significant differences in attenuation between regions for which there is sufficient data to construct a relation between I_s and ground motion for a range of epicentral intensities. In addition there is insufficient data to develop refined models to account for the difference between magnitude scale used in the various regions. G-Expert 5 selected the relation G-16 of Q10 between intensity and PGA (Trifunac 1976) and the model TL-RS (Trifunac and Lee (1985)) between intensity and spectral values.

The model selected by G-Expert 5 is entirely data based which is more than can be said for the other models except for the lightly weighted model Comb-1A. In addition the model selected by G-Expert 5 and the lightly weighted Comb-1A are the only intensity based models selected. The argument for intensity based models is that they are the only direct ground motion data we have from the larger EUS earthquakes. The argument against intensity based models are that: (1) they have poor correlation, i.e., one needs a large value for the error term, e.g., the value selected by G-Expert 5 is consistent with data, and if anything smaller, and (2) one does not have the data to develop the proper relation between distance ground motion and site intensity to substitute into the attenuation of intensity with distance relation.

The fact that results obtained by using the ground motion model of G-Expert 5 (labeled G16-A3) appear in many ways different, in general higher, than when using the other models motivated a careful reanalysis of this model. Our first step in quality control was to perform extensive auditing of all the questionnaire responses and to perform numerous sensitivity analyses to analyze the behavior of G16-A3 with respect to the seismic hazard, to ensure that everything we would observe was consistent with our understanding of the data.

Then, in addition to the formal feedback questionnaires and meetings organized in this project (Q4, Q7 and Q10), we had an extra one-on-one feedback meeting with G-Expert 5. In that meeting, we described again the versions of the models used in our analysis and studied together the results of the sensitivity analyses. We emphasized how the sites corrections were used as well as the type of seismicity and zonation models used in the analysis.

This quality control confirmed that the models attributed to G-Expert 5 and the way we used them was consistent with Expert's 5 understanding of the problem and of the project's limitations. Since G16-A3 carries approximately 20 percent of the weight of the ground motion models, we reviewed the various elements of this specific model which make it desirable or undesirable for use in a seismic hazard analysis for the E.U.S.

In essence, there are three parts to the derivation of G16-A3. They are:

1. The model of attenuation

2. The scaling of earthquake size

3. The correlation between site intensity and ground motion acceleration or velocity

In addition (item 4), the correlation between magnitude and intensity. Although not really a part of the model, a relationship is used in our analysis. When the seismicity parameter are expressed in term of magnitude, the relationship between magnitude and intensity is used to convert intensity into magnitude, and vice-versa when the seismicity is in intensity and the ground motion model is in magnitude. Items 1 and 2 are relying entirely on E.U.S. intensity data since it is modeled by the Gupta-Nuttli relationship.

Item 3 relies mostly on strong motion data from the Western U.S. As such, one might question its applicability to the E.U.S. To our knowledge, however, there is no definitive work showing that the use of Western U.S. strong motion data to correlate site intensity with PGA/or PGV would not apply to the E.U.S.

Some of the sites in the E.U.S. are located on rock (approximately 47% of them), some are located on deep soil (approximately 17% of them) and the remaining ones (approximately 36% of them) are located on shallow soil. More research is needed at the present time to clarify whether there is significant difference, for each site condition considered, in the relationship of PGA (or PGA) versus I_s, between the Eastern U.S. and the Western U.S., for the same soil conditions and for the same site intensity (I_s).

The additional item mentioned above (item 4) is a relationship between magnitude and epicentral distance which was developed with Eastern U.S. data.

Given the paucity of ground motion data from even relatively small earthquakes (up to m_b=5) in the EUS and the total lack of measured data from large EUS earthquakes, it is in our view necessary to include intensity based models in the analysis. However, it must also be recognized that in an analysis such as we are performing, certain combinations of assumptions will lead to estimates that are true outliers. Ideally in such cases one would review both the seismicity assumptions, ground motion model assumptions and/or the weights selected to see if there isn't a better set of seismicity and ground motion models and weights that should be used. Clearly, in our case where we have one set of experts providing the seismicity input and a different set providing the ground motion models, it is difficult to do this reconsideration of the input. This in our opinion makes the AMHC a relatively poor choice to use to compare the hazard between sites because it is more sensitive to outliers than other estimators, such as the median, or other percentiles. On the other hand, given the spread between expert opinion observed in this study the variation in the median CPHC is relatively small between the case when S-Expert 5 is included or not included. This in our view makes the median estimate a very desirable estimator, given its relatively high stability. Thus we would recommend making the needed assessments and comparisons between sites relative to the median CPHCs and median CPUHS with all of the S- and G-Experts included. However, any assessment must account for the large uncertainty in the seismic hazard that exists.

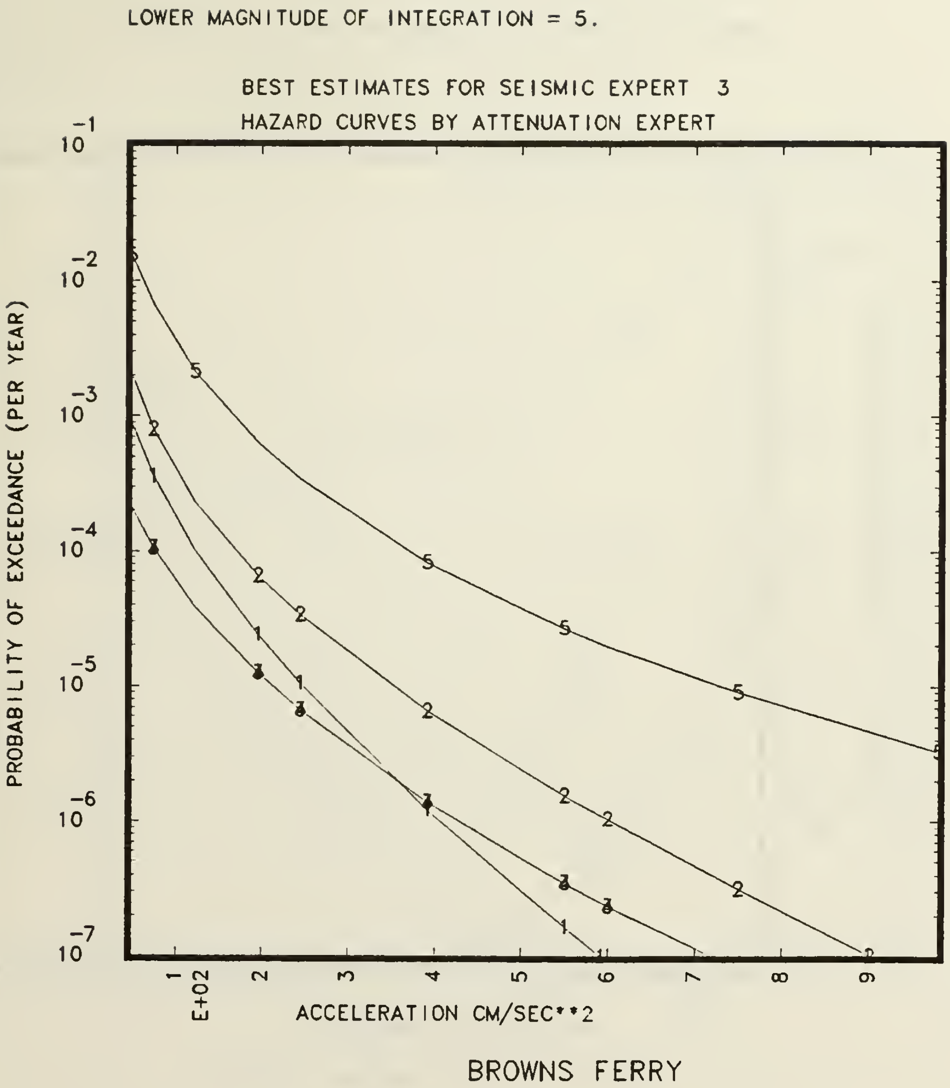
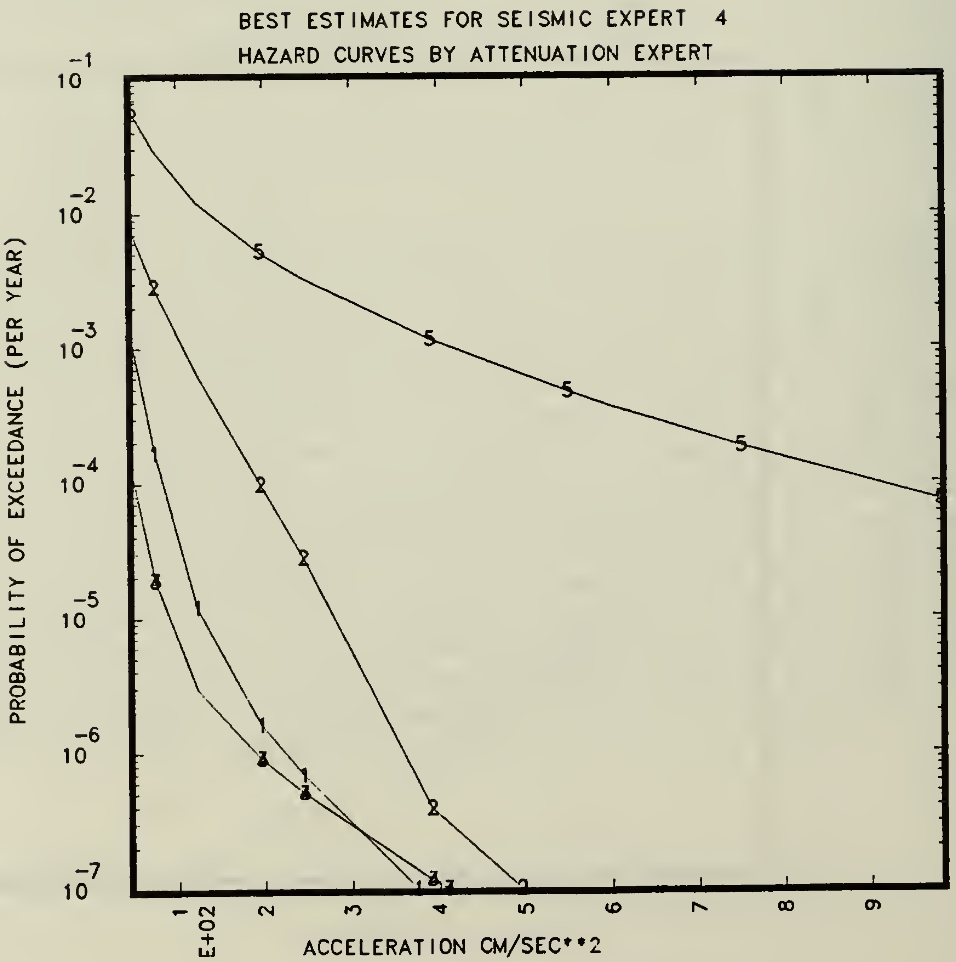


Figure 2.3.1a Comparison between the BEHCs per G-Expert for S-Expert 3's input for the Browns Ferry site.

LOWER MAGNITUDE OF INTEGRATION = 5.



BROWNS FERRY

Figure 2.3.1b Comparison between BEHCs per G-Expert for S-Expert 4's input for the Browns Ferry site.

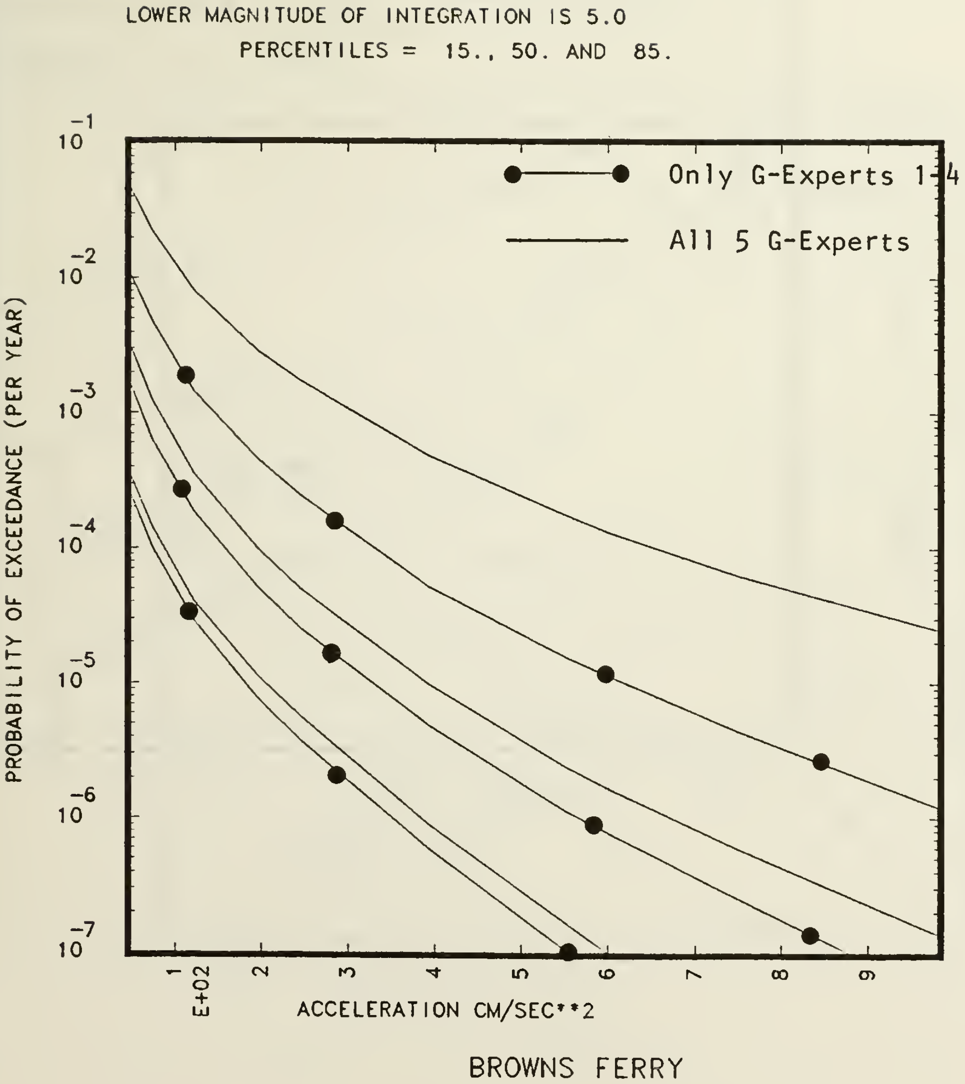


Figure 2.3.2a Comparison between the CPHCs when all 5 G-Experts are used and when G-Experts is not included for the Browns Ferry site.

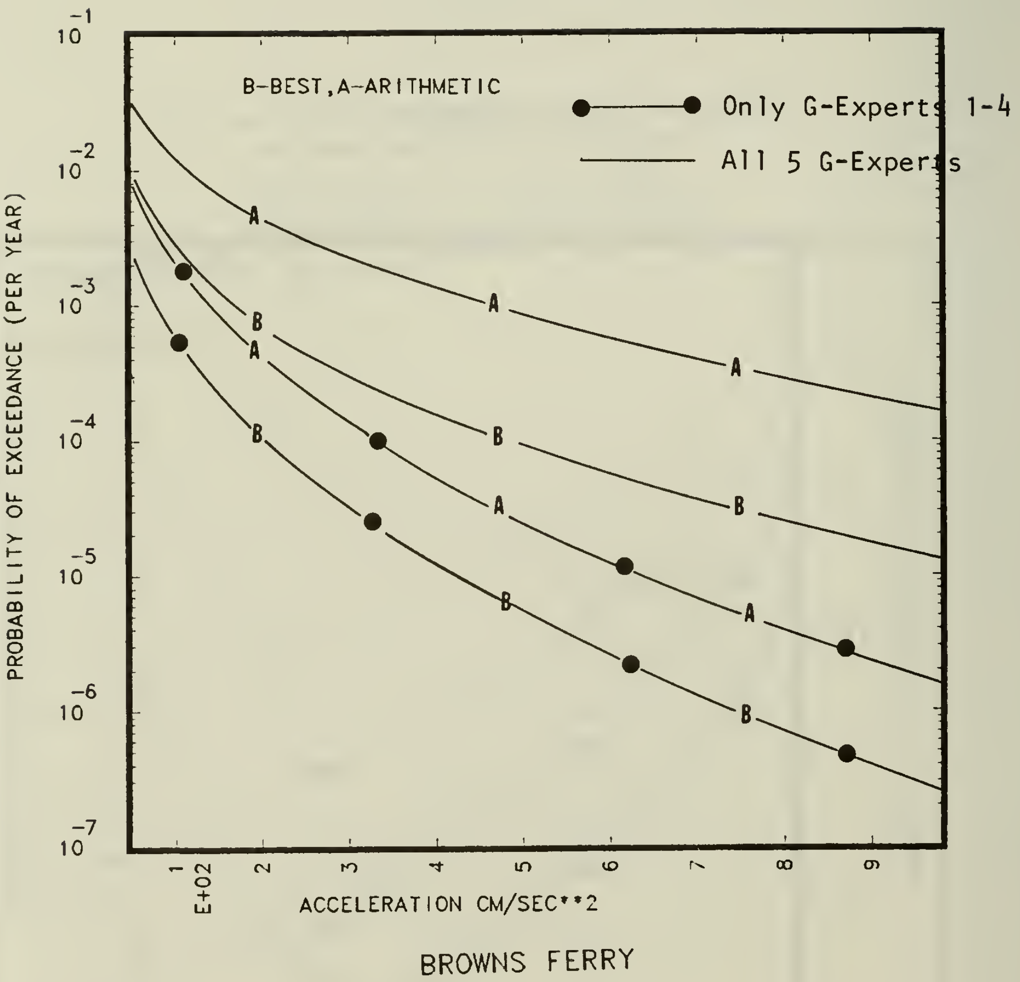


Figure 2.3.2b Comparison between the AMHCs and BEHCs when all 5 G-Experts are used and when G-Expert 5 is not included for the Browns Ferry site.

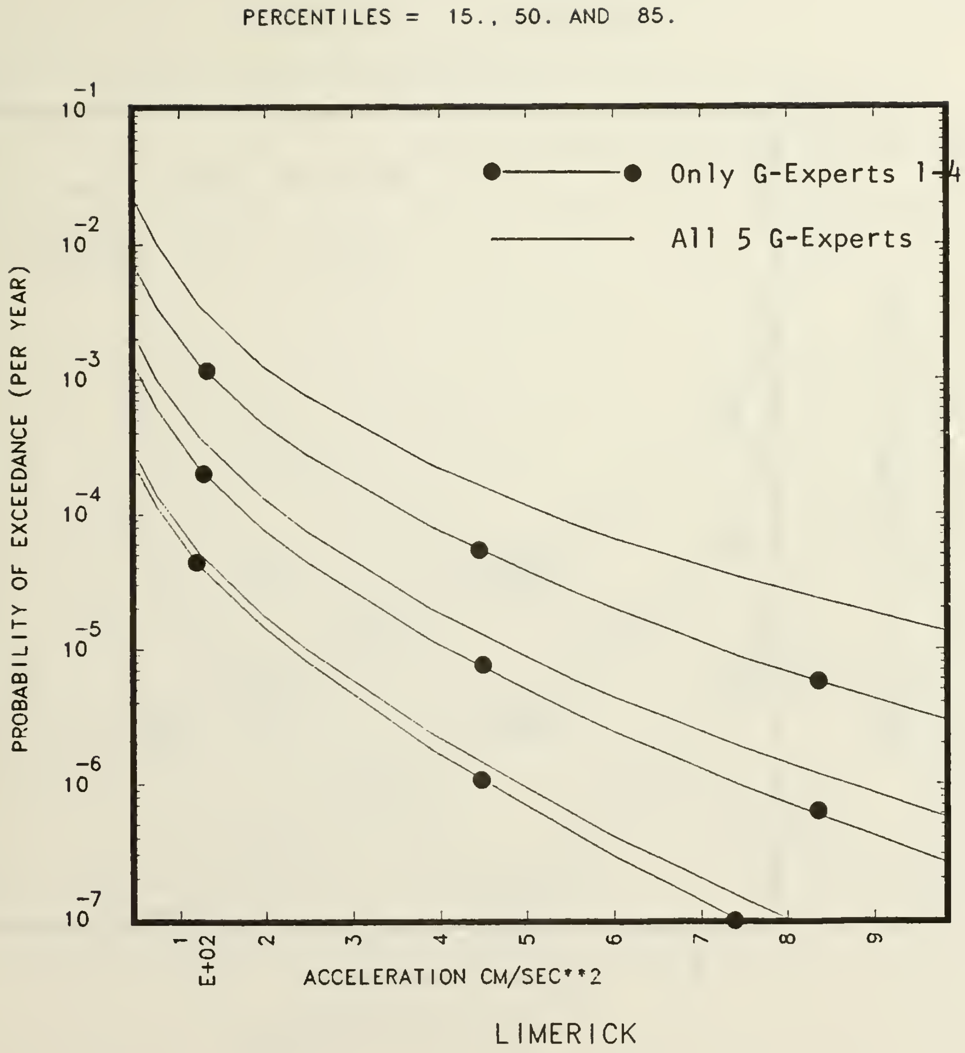


Figure 2.3.3 Comparison between the CPHCs when all the G-Experts are used and when G-Expert 5 is not included for the Limerick site.

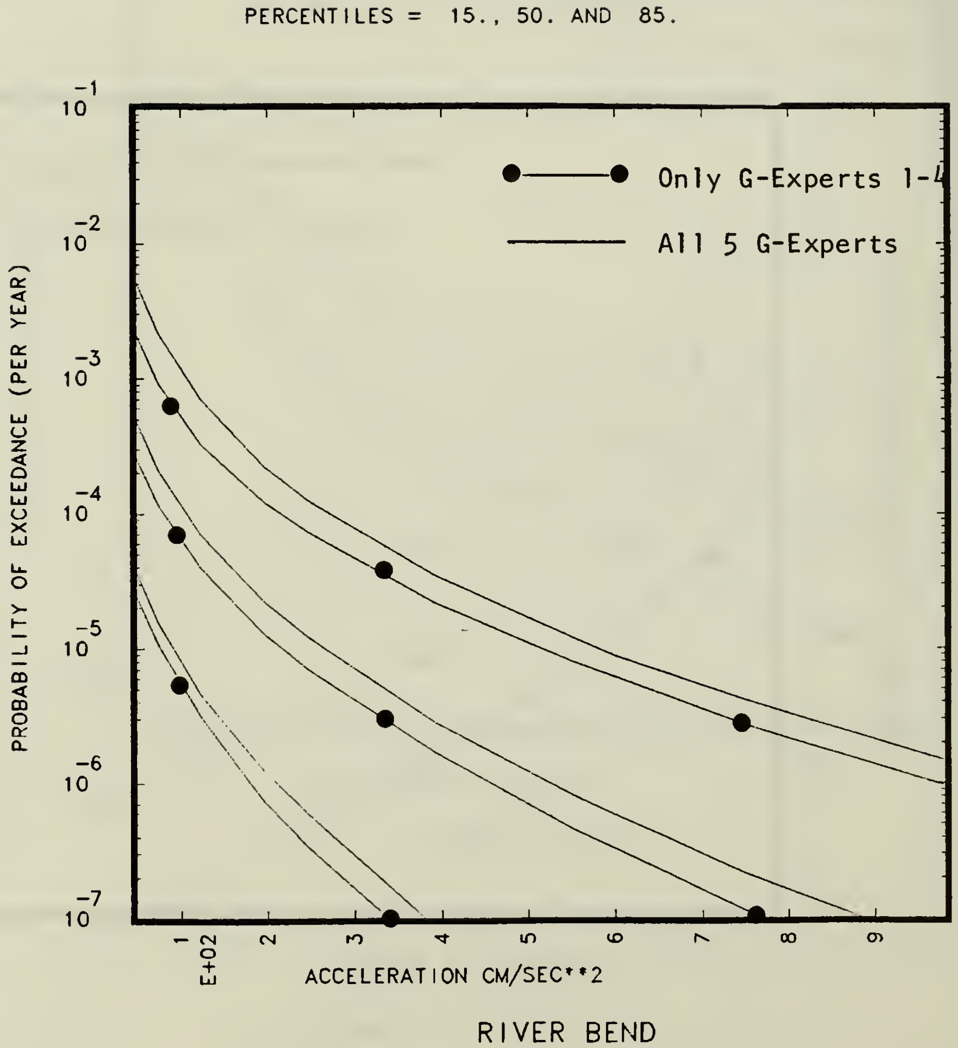


Figure 2.3.4 Comparison between CPHCs when all of the G-Experts are used and when G-Expert 5 is not included for the River Bend site.

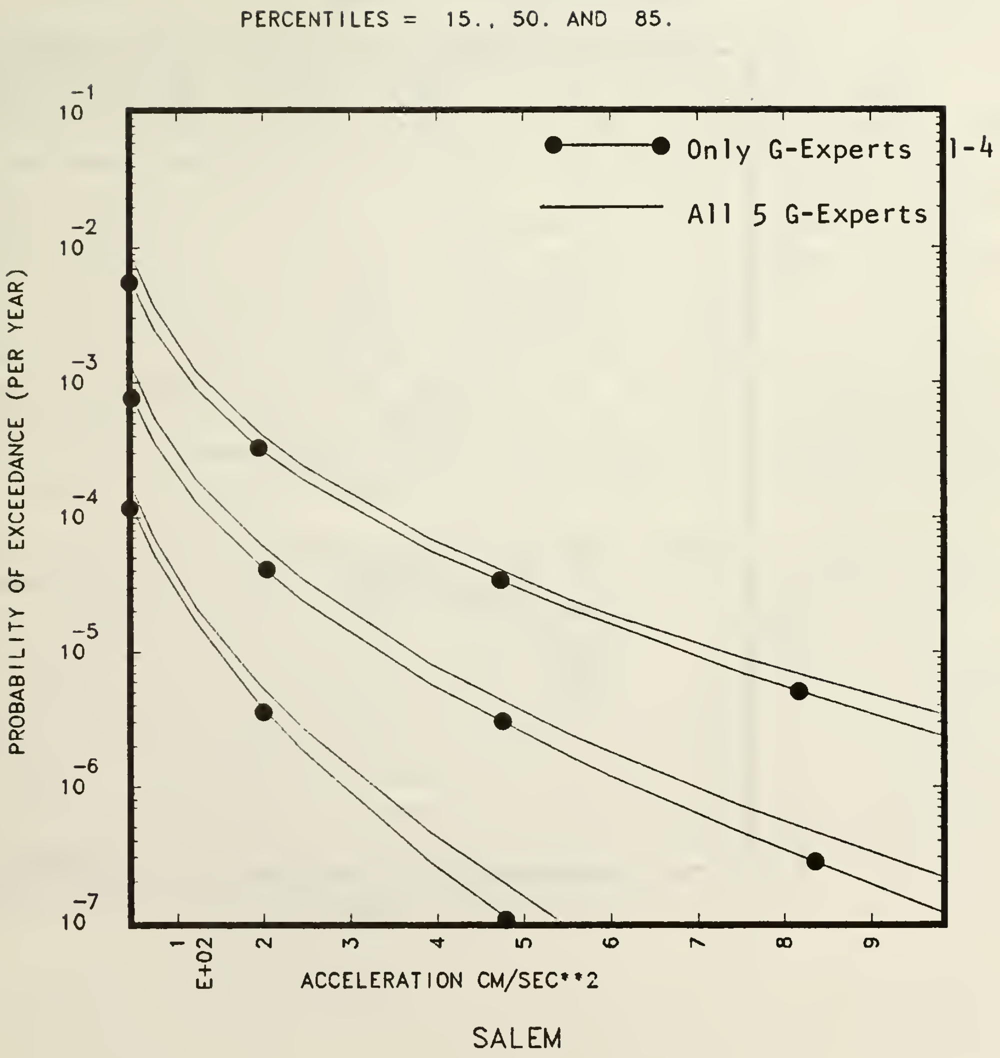


Figure 2.3.5 Comparison between the CPHCs when all of the G-Experts are used and when G-Expert 5 is not included for the Salem site.

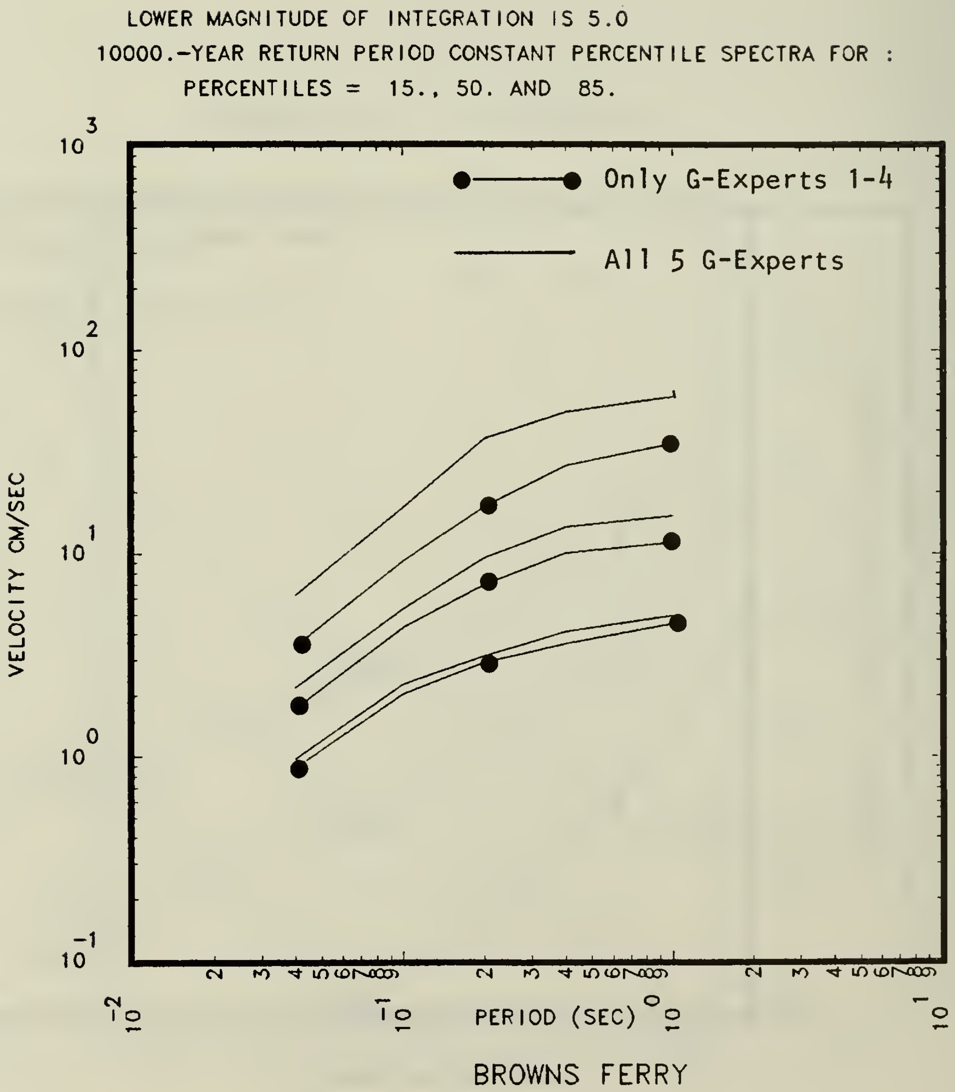


Figure 2.3.6 Comparison between the 10,000 year return period CPUHS when all of the G-Experts are used and when G-Expert 5 is not included for the Browns Ferry site.

2.4 Apparent Disconnect Between the PGA Hazard and the Spectral Hazard

Based on a number of studies, e.g., Newmark and Hall (1978), it has been the custom to assume that at approximately 33Hz the spectral amplification of the PGA is unity. In Fig. 2.4.1 we have converted the CPHCs at the appropriate probability of exceedance to spectra values and plotted them on the 10,000 return period CPUHS for the Limerick site. It is evident from Fig. 2.4.1 that there is a "disconnect" between the high frequency end of the CPUHS, the PGA and the assumed spectral amplification factor at 33Hz. The apparent disconnect arises because of the EUS random vibration models, which are heavily weighted by our G-Experts, have much higher amplification factors at short periods than typical western U.S. earthquakes. This is illustrated in Fig. 2.4.2. In Fig. 2.4.2 we compare the spectral model based on a Newmark-Hall model, i.e., standard western U.S. spectral amplification factors, developed using a random vibration PGA and velocity models (see Vol. 1 models RV-5A and RV-5V) and the resultant spectral model based on the same assumptions (model RV-5RS) used to develop the PGA and velocity models used with the Newmark-Hall amplification factors. We see that the resultant spectral shapes are significantly different. The random vibration spectral model has significantly more short period content than the Newmark-Hall spectral model and significantly less longer period energy than the Newmark-Hall model. This difference between the RV-spectral models and either Newmark-Hall type models or the model selected by G-Expert 5 lead to the results shown in Fig. 2.4.1 where the CPUHS at 25Hz are high relative to the PGA hazard curve. Additionally, the long period difference leads to the increased uncertainty at 1 sec as compared to 0.04 secs in our CPUHS typically plotted in Vols. II-V. See Q10 in Vol. VII for additional discussion of the difference between the RV models and "typical" western U.S. spectral models.

It should be noted that this "disconnect" may have important implications for the stiff components of nuclear power plants. For such equipment (natural period shorter than 0.05 sec.) it has been customary to assume that the spectral acceleration they are subject to is equal to the PGA. Clearly, as can be seen from Figs. 2.4.1 and 2.4.2 that this is a poor assumption in the EUS. The EUS RV-spectral models amplify the PGA for periods longer than 0.1 sec. Typically, the PGA should be converted to spectral acceleration and plotted at 0.01s. The spectrum between 0.01 sec. and 0.04 sec. (last point computed) can be approximated by connecting the 0.01 spectral value estimated by converting the PGA hazard to a spectral velocity with unity amplification factor with the 0.04 value of the CPUHS plotted on the various figures by a straight line. This is illustrated in Fig. 2.4.3.

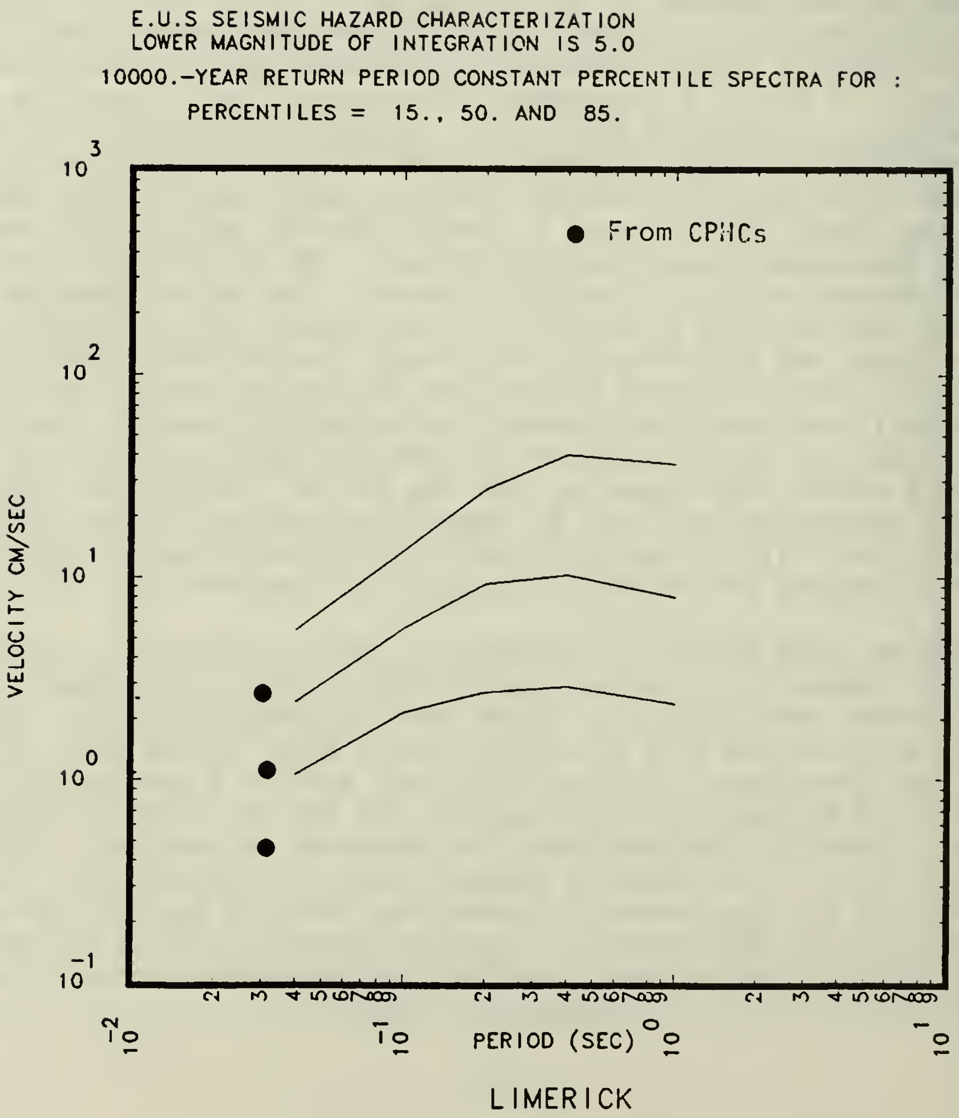


Figure 2.4.1 Comparison between the 10,000 year return period CPUHS for the Limerick site and the spectral value estimated from the CPHCs using the Newmark-Hall amplification of 1.0 at 0.03 sec. to convert acceleration to relative velocity.

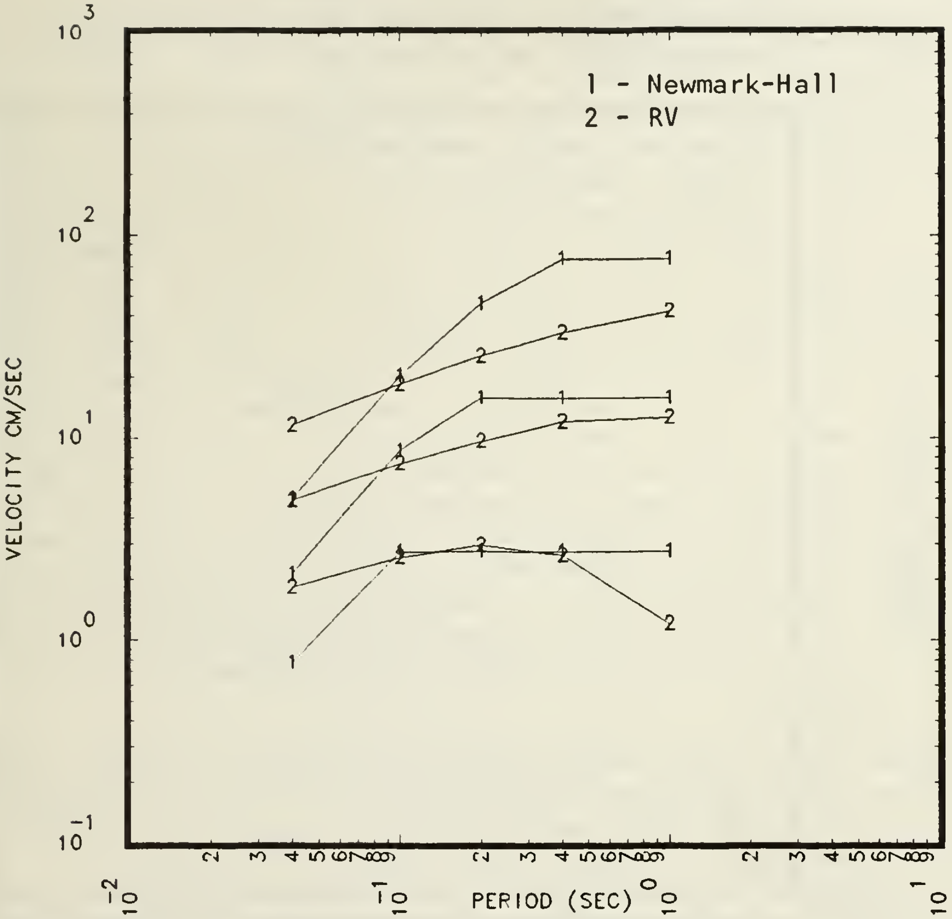


Figure 2.4.2 Comparison between the spectra obtained using the random vibration spectral model RV-5RS at an epicentral distance of 15km for magnitudes 5, 6 and 7 and the spectra obtained using the Newmark-Hall median spectral amplifications applied to the random vibration acceleration model RV-5A and random vibration velocity model RV-5V. The models RV-5A and 5V are consistent with the spectral model RV-5RS.

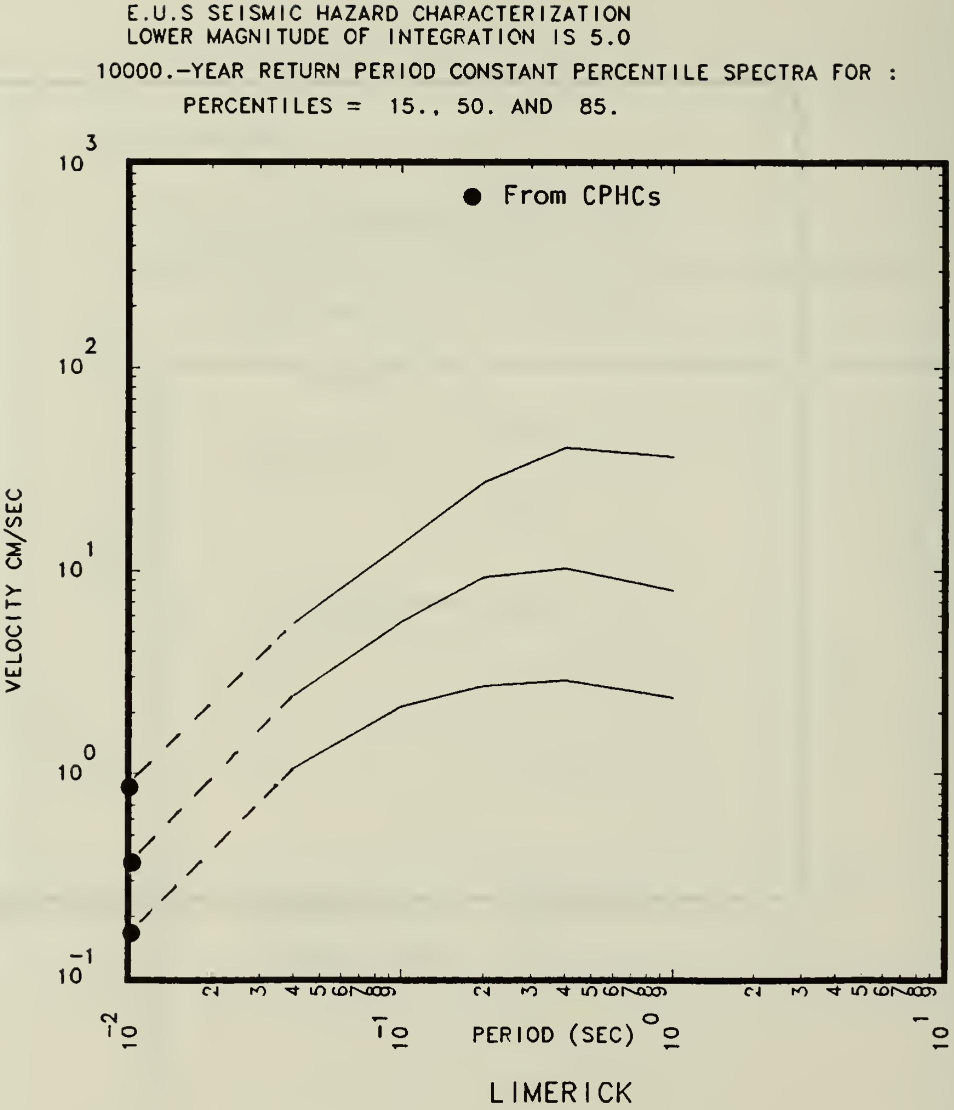


Figure 2.4.3 Illustration of how the spectral values for periods shorter than 0.04S can be estimated. The appropriate PGA value is read from off the CPHCs at the appropriate return period, converted to spectral velocity and plotted at 0.01s. Then a straight line, as shown, is used to connect the PGA value to the last computer CPUHS value at 0.04s.

3. COMPARISON BETWEEN SITES AND REGIONAL OBSERVATIONS

3.1 General Comparisons Between Sites

In Fig. 3.1.1a we plot the median CPHC for all 69 sites included in this study. In Figs. 3.1.1b-e we plot the median hazard curves for each of the batches individually. The plot symbols used in Figs. 3.1.1b-e correspond to the identifications given in Tables 1.1a-d respectively. We see that there is a relatively wide spread between the site with the lowest and highest median CPHC. In Fig. 3.1.1a the two sites with highest median CPHC are the Seabrook and Pilgrim sites. However, we have pointed out a number of times that because the uncertainty is large the use of other estimators could lead to a different ordering of the sites. This point is illustrated in Fig. 3.1.2a and b for which the key to the identity of the sites is given in Tables 3.1.1 and 3.1.2. In Fig. 3.1.2a, b we plot for each site the median (plot symbol M), the best estimate (B), the arithmetic mean (A) and the 15th and 85th percentiles (*) annual probabilities of exceeding 0.2g PGA. In Fig. 3.1.2a the sites are ordered by Volume; e.g., the sites in Vol. II are 1-19, in Vol. III they are 20-36, in Vol. IV they are 37-52 and in Vol. V they are 53-69. In Fig. 3.1.2b the sites have been ordered by the median hazard at 0.2g. This ordering, as well as the original ordering, is given in Tables 3.1.1 and 3.1.2. We see from Fig. 3.1.2b that a very different ordering of the sites would result if we used say the BEHC or the AMHC. Clearly, the AMHC shows the largest variation of any of the estimators. We have pointed this out a number of times in Vols. II-V in our discussions of the various sites; e.g., see Vol. V Section 2.16 for the Waterford site (#68 in the ordering in Fig. 3.1.2a).

We see from either Fig. 3.1.2 a or b that at the 0.2g level there is approximately 2 orders of magnitude spread between the 15th and 85th percentile CPHCs. In fact the largest spread between the 15th and 85th percentile CPHCs at 0.2g occurs at the Callaway site (#54 in Fig 3.1.2a and #46 in Fig. 3.1.2b) where the spread is 2.5 orders of magnitude. The smallest spread between the 15th and 85th CPHCs at 0.2g occurs at the Zion site (#52 in Fig. 3.1.2a and #32 in Fig. 3.1.2b) where the spread is 1.8 orders of magnitude. It is somewhat interesting to note that the site with the largest and smallest spread between the 15th and 85th CPHCs at 0.2g are both in the Central Stable region. We also see from Fig. 3.1.2, on the average, that the spread between the median CPHCs for all sites at 0.2g is about 1.4 orders of magnitude.

We see from Figs. 3.1.1a-e that at higher g-levels a number of the median hazard curves cross, e.g., at low g values Seabrook (symbol E in Fig. 3.1.1b) has a higher median hazard for PGA than the Pilgrim site (symbol C in Fig. 3.1.1b), but at higher g-values the Pilgrim site has a higher median hazard for PGA. We also see from Figs. 3.1.1a-e that at higher g levels, the spread between the median CPHCs becomes larger. However, the uncertainty also grows. For example, Fig. 3.1.3 (for which the key to site identity is given in Table 3.1.3), shows that at the 0.6g level there is a 1.6 order of magnitude spread between the median hazard values from the site with the highest median hazard to the site with the lowest median hazard. The largest

spread between the 15th and 85th percentile CPHCs at 0.6g is 3.4 orders of magnitude (for the Grand Gulf site, #63 in Fig. 3.1.3) and the smallest spread between the 15th and 85th percentile CPHCs at 0.6g is 2.1 orders of magnitude (for the Three Mile Island site, site #15 in Fig. 3.1.3). Thus the uncertainty at 0.6g has grown at a slightly larger rate than the variation between the median CPHCs. It is also important to note from Fig. 3.1.1a that, at say the 10^{-4} probability of exceedance level, the median PGA for the sites only varies by a factor of 4 whereas (as previously noted) at the 0.2g level the median probability of exceedance varies by a factor of 26. Thus the somewhat large variations in probability of exceedance that exist result in a much smaller uncertainty in the ground motion level.

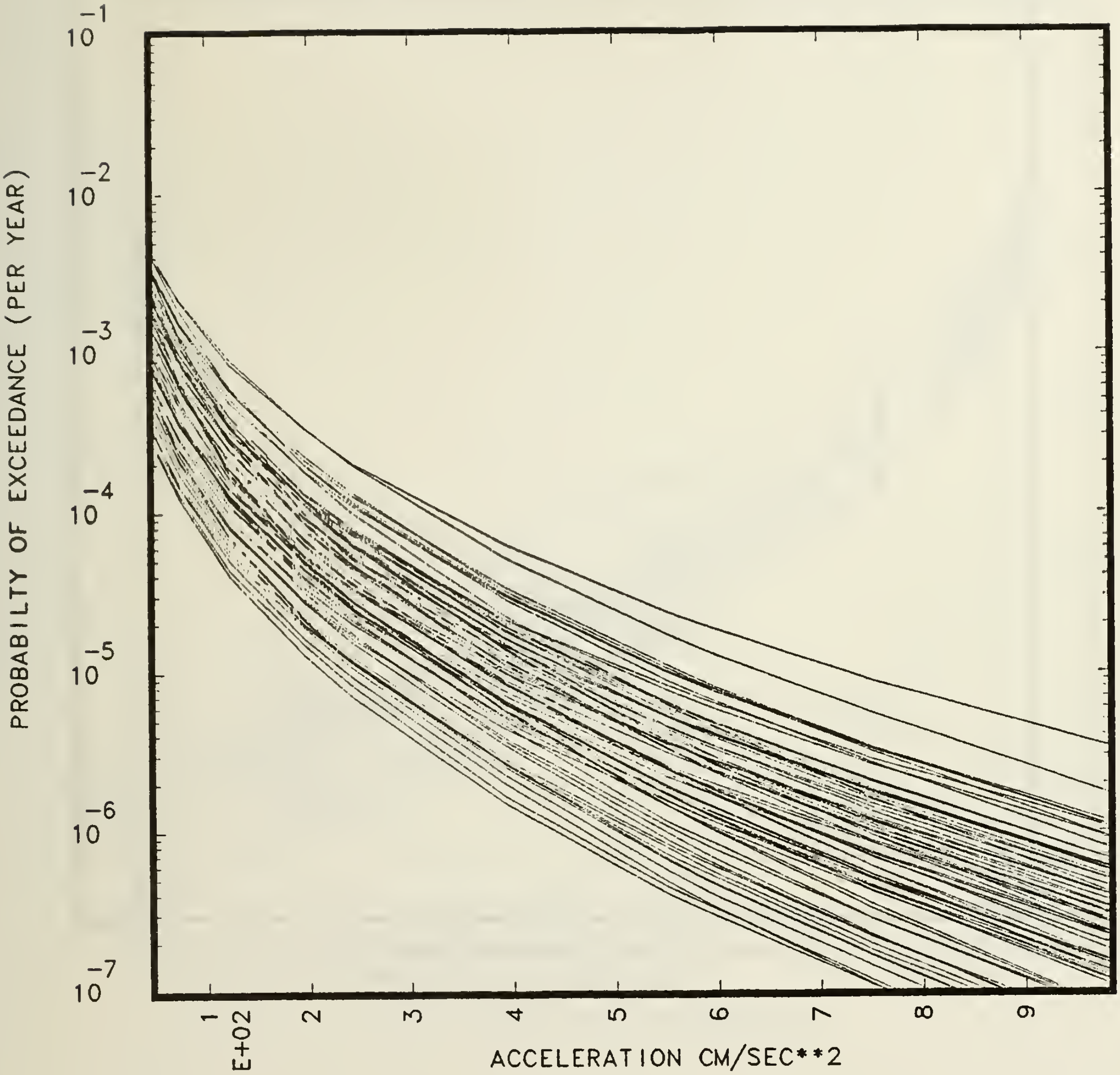


Figure 3.1.1a Comparison of the median CPHCs for all of the sites listed in Tables 1.1a-d.

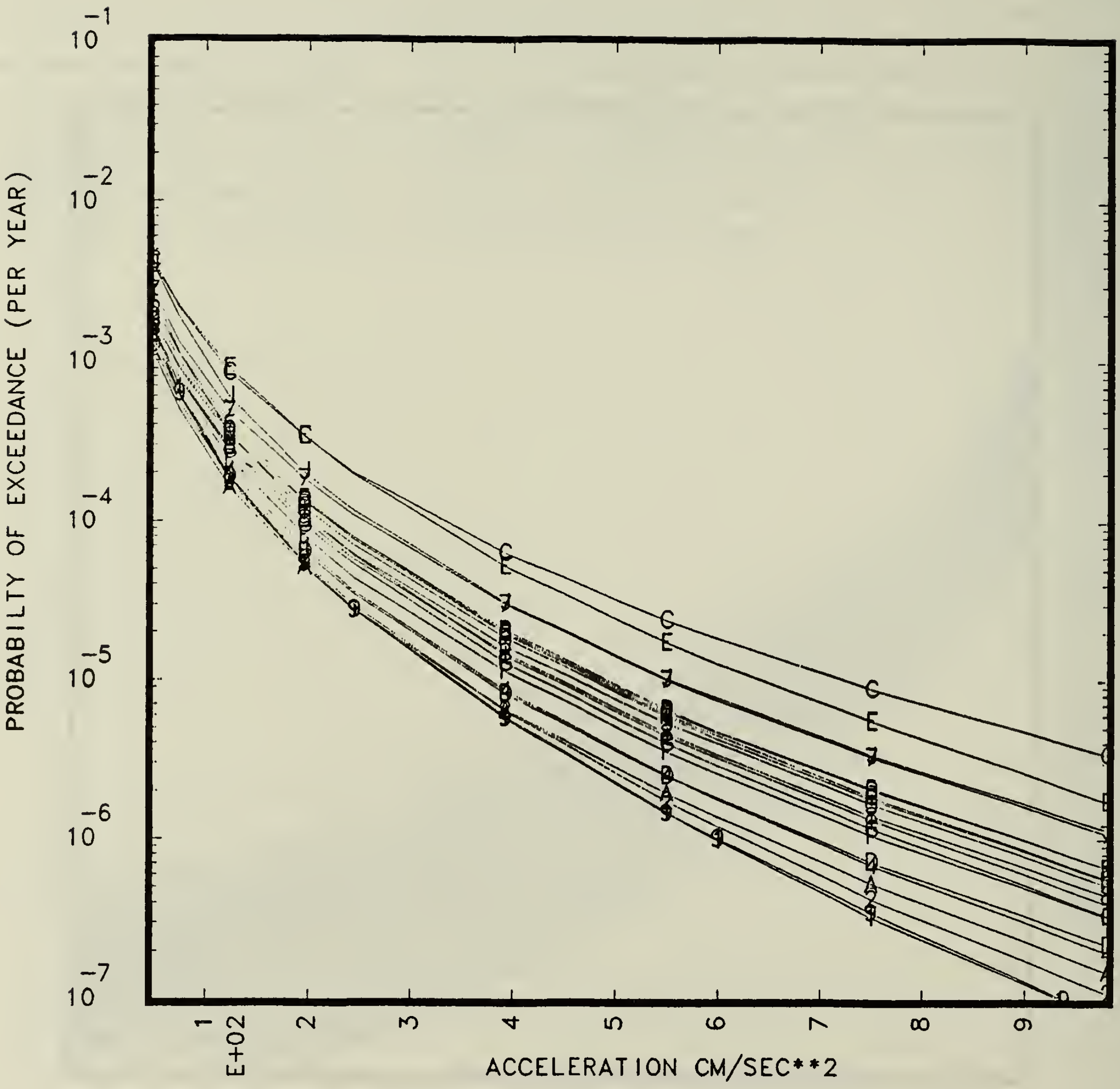


Figure 3.1.1b Comparison of the median CPHCs for the sites in Vol. II. The plot symbols used to identify the sites are given in Table 1.1a.

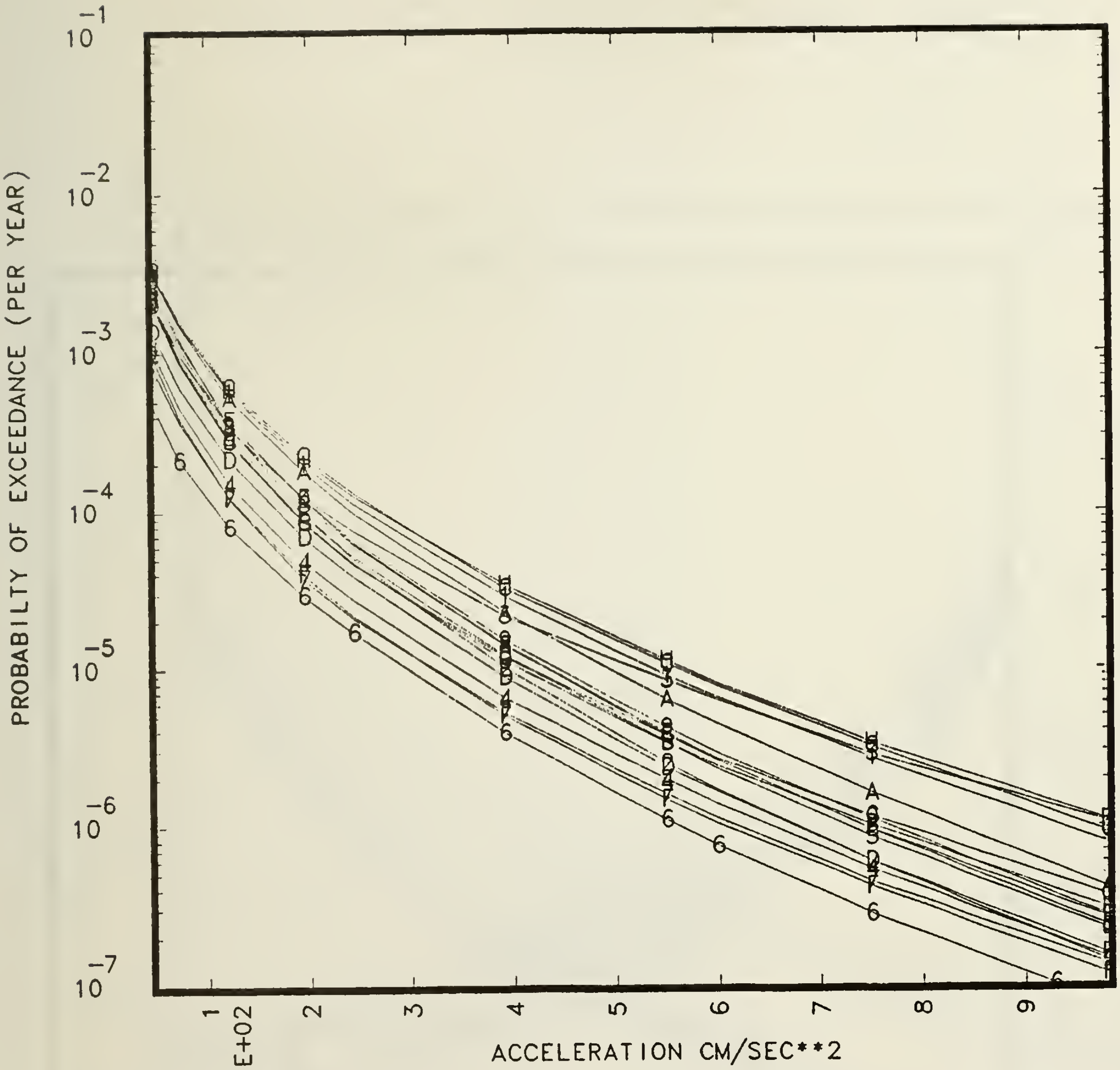


Figure 3.1.1c Comparison of the median CPHCs for the sites in Vol. III. The plot symbols used to identify the sites are given in Table 1.1b.

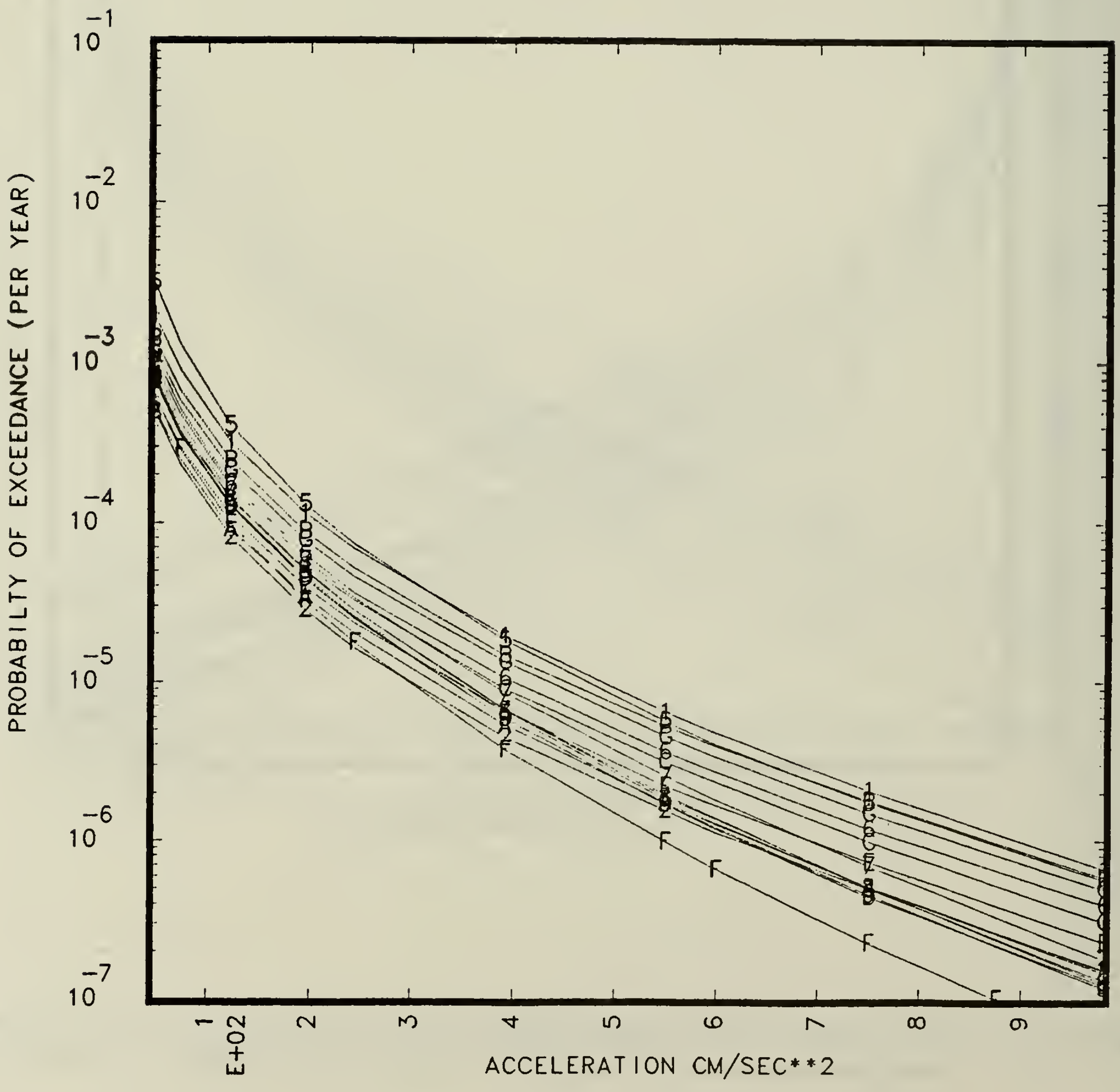


Figure 3.1.1d Comparison of the median CPHCs for the sites in Vol. IV. The plot symbols used to identify the sites are given in Table 1.1c.

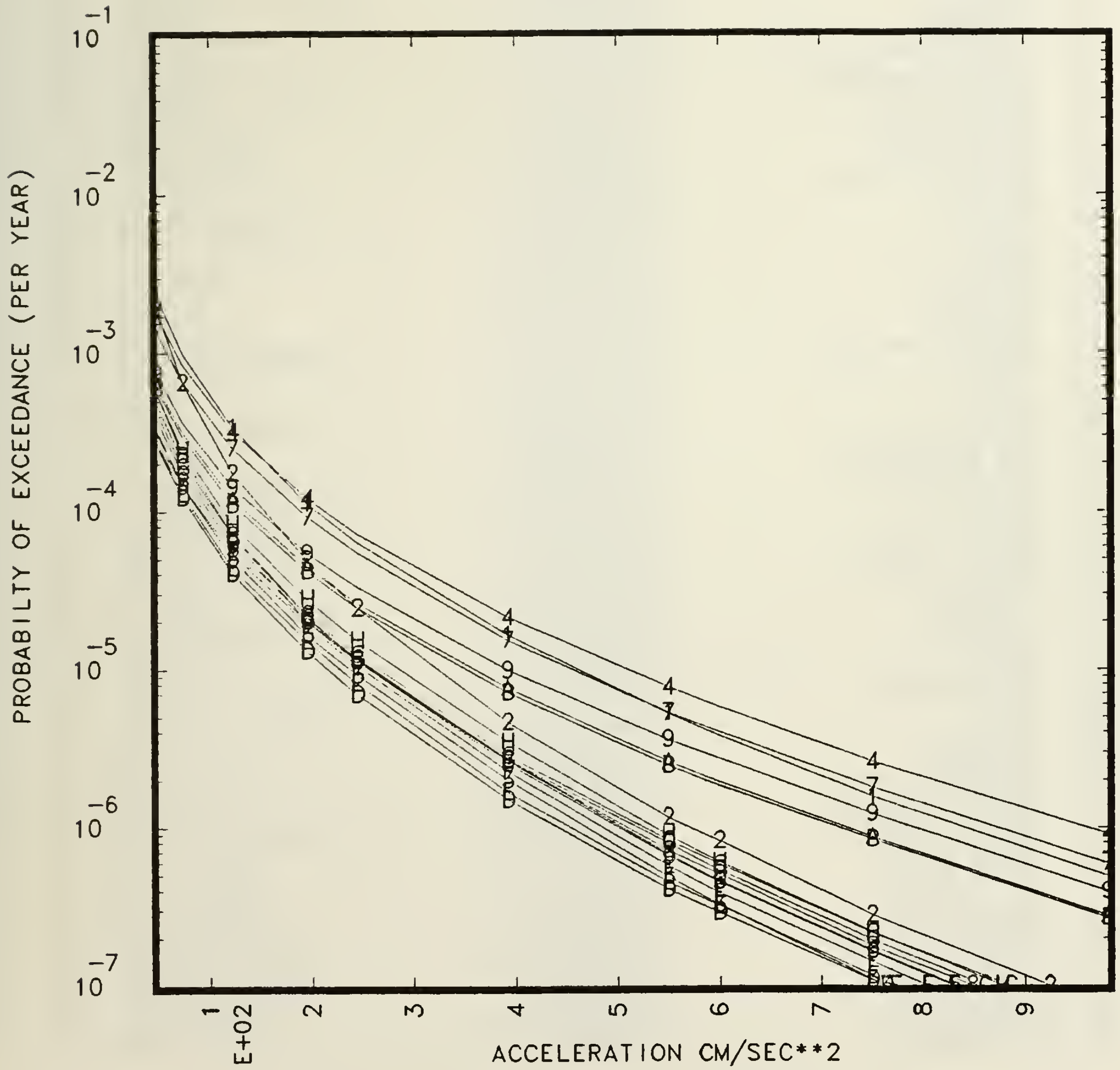


Figure 3.1.1e Comparison of the median CPHCs for the sites in Vol. V. The plot symbols used to identify the sites are given in Table 1.1.d.

TABLE 3.1.1
KEY FOR SITES IN FIGURE 3.1.2a AND 3.1.2b

(1)	(2)		(3)
41	1	FITZPATRICK	.5368E-04
38	2	GINNA	.5656E-04
22	3	HADDAM NECK	.1062E-03
34	4	HOPE CREEK	.6818E-04
9	5	INDIAN POINT	.1380E-03
10	6	LIMERICK	.1350E-03
7	7	MAINE YANKEE	.1838E-03
23	8	MILLSTONE	.1010E-03
40	9	NINE MILE POINT	.5374E-04
43	10	OYSTER CREEK	.5132E-04
11	11	PEACH BOTTOM	.1323E-03
2	12	PILGRIM	.3383E-03
35	13	SALEM	.6388E-04
1	14	SEABROOK	.3406E-03
31	15	SHOREHAM	.8080E-04
26	16	SUSQUEHANNA	.9442E-04
14	17	THREE MI. ISLAND	.1219E-03
19	18	VERMONT YANKEE	.1132E-03
5	19	YANKEE ROWE	.2017E-03
6	20	BELLEFONTE	.2014E-03
24	21	BROWNS FERRY	.9930E-04
13	22	BRUNSWICK	.1245E-03
47	23	CALVERT CLIFFS	.4897E-04
25	24	CATAWBA	.9606E-04
58	25	FARLEY	.2932E-04
55	26	HATCH	.3767E-04
20	27	MCGUIRE	.1124E-03
16	28	NORTH ANNA	.1214E-03
8	29	OCONEE	.1818E-03
29	30	ROBINSON	.8762E-04
3	31	SEQUOYAH	.2264E-03
33	32	SHEARON HARRIS	.6917E-04
17	33	SUMMER	.1210E-03
53	34	SURRY	.4017E-04
30	35	VOGTLE	.8597E-04
4	36	WATTS BAR	.2151E-03
18	37	BEAVER VALLY	.1148E-03
59	38	BIG ROCK POINT	.2824E-04
48	39	BRAIDWOOD	.4660E-04
44	40	BYRON 1 & 2	.5060E-04
12	41	CLINTON	.1309E-03
36	42	COOK 1 & 2	.6330E-04
37	43	DAVIS BESSE 1	.5826E-04
45	44	DRESDEN 2&3	.4955E-04
51	45	FERMI 2	.4437E-04
56	46	KEWAUNEE	.3434E-04
28	47	LASALLE	.8805E-04
42	48	PALISADES 1	.5332E-04
50	49	PERRY	.4447E-04
54	50	POINT BEACH	.3936E-04
57	51	QUAD CITIES	.3244E-04
32	52	ZION	.7786E-04
21	53	ARKANSAS	.1123E-03
46	54	CALLAWAY	.4951E-04
67	55	COMANCHE PEAK	.1666E-04
15	56	COOPER	.1215E-03
65	57	CRYSTAL RIVER	.2011E-04
63	58	DUANE ARNOLD	.2126E-04
27	59	FORT CALHOUN	.9263E-04
62	60	GRAND GULF	.2175E-04
39	61	LA CROSSE	.5448E-04
49	62	MONTICELLO	.4510E-04
52	63	PRAIRIE ISLAND	.4189E-04
61	64	RIVER BEND	.2238E-04
69	65	SOUTH TEXAS	.1311E-04
68	66	ST. LUCIE	.1517E-04
66	67	TURKEY POINT	.1934E-04
64	68	WATERFORD	.2045E-04
60	69	WOLF CREEK	.2807E-04

Column (1) is for the site numbers for Fig. 3.1.2b
Column (2) is for the site numbers in Fig. 3.1.2a (i.e., order in Vol. I)
Column (3) is the median hazard value of 0.2g

TABLE 3.1.2
KEY FOR SITES IN FIGURE 3.1.2a AND 3.1.2b
AND MEDIAN VALUES AT 0.2g

(1)	(2)		(3)
1	14	SEABROOK	.3406E-03
2	12	PILGRIM	.3383E-03
3	31	SEQUOYAH	.2264E-03
4	36	WATTS BAR	.2151E-03
5	19	YANKEE ROWE	.2017E-03
6	20	BELLEFONTE	.2014E-03
7	7	MAINE YANKEE	.1838E-03
8	29	OCONEE	.1818E-03
9	5	INDIAN POINT	.1380E-03
10	6	LIMERICK	.1350E-03
11	11	PEACH BOTTOM	.1323E-03
12	41	CLINTON	.1309E-03
13	22	BRUNSWICK	.1245E-03
14	17	THREE MI. ISLAND	.1219E-03
15	56	COOPER	.1215E-03
16	28	NORTH ANNA	.1214E-03
17	33	SUMMER	.1210E-03
18	37	BEAVER VALLY	.1148E-03
19	18	VERMONT YANKEE	.1132E-03
20	27	MCGUIRE	.1124E-03
21	53	ARKANSAS	.1123E-03
22	3	HADDAM NECK	.1062E-03
23	8	MILLSTONE	.1010E-03
24	21	BROWNS FERRY	.9930E-04
25	24	CATAWBA	.9606E-04
26	16	SUSQUEHANNA	.9442E-04
27	59	FORT CALHOUN	.9263E-04
28	47	LASALLE	.8805E-04
29	30	ROBINSON	.8762E-04
30	35	VOGTLE	.8597E-04
31	15	SHOREHAM	.8080E-04
32	52	ZION	.7786E-04
33	32	SHEARON HARRIS	.6917E-04
34	4	HOPE CREEK	.6818E-04
35	13	SALEM	.6388E-04
36	42	COOK 1 & 2	.6330E-04
37	43	DAVIS BESSE 1	.5826E-04
38	2	GINNA	.5656E-04
39	61	LA CROSSE	.5448E-04
40	9	NINE MILE POINT	.5374E-04
41	1	FITZPATRICK	.5368E-04
42	48	PALISADES 1	.5332E-04
43	10	OYSTER CREEK	.5132E-04
44	40	BYRON 1 & 2	.5060E-04
45	44	DRESDEN 2&3	.4955E-04
46	54	CALLAWAY	.4951E-04
47	23	CALVERT CLIFFS	.4897E-04
48	39	BRAIDWOOD	.4660E-04
49	62	MONTICELLO	.4510E-04
50	49	PERRY	.4447E-04
51	45	FERMI 2	.4437E-04
52	63	PRAIRIE ISLAND	.4189E-04
53	34	SURRY	.4017E-04
54	50	POINT BEACH	.3936E-04
55	26	HATCH	.3767E-04
56	46	KEWAUNEE	.3434E-04
57	51	QUAD CITIES	.3244E-04
58	25	FARLEY	.2932E-04
59	38	BIG ROCK POINT	.2824E-04
60	69	WOLF CREEK	.2807E-04
61	64	RIVER BEND	.2238E-04
62	60	GRAND GULF	.2175E-04
63	58	DUANE ARNOLD	.2126E-04
64	68	WATERFORD	.2045E-04
65	57	CRYSTAL RIVER	.2011E-04
66	67	TURKEY POINT	.1934E-04
67	55	COMANCHE PEAK	.1666E-04
68	66	ST. LUCIE	.1517E-04
69	65	SOUTH TEXAS	.1311E-04

Column (1) is for the site numbers for Fig. 3.1.2b
Column (2) is for the site numbers in Fig. 3.1.2a (i.e., order in Vol. I)
Column (3) is the median hazard value of 0.2g

TABLE 3.1.3
KEY FOR SITES IN FIGURE 3.1.3 AND MEDIAN HAZARD VALUES FOR 0.6g

(1)	(2)		(3)
1	12	PILGRIM	.1844E-04
2	14	SEABROOK	.1269E-04
3	36	WATTS BAR	.7950E-05
4	19	YANKEE ROWE	.7693E-05
5	31	SEQUOYAH	.7658E-05
6	7	MAINE YANKEE	.7427E-05
7	20	BELLEFONTE	.6441E-05
8	22	BRUNSWICK	.6278E-05
9	56	COOPER	.5789E-05
10	37	BEAVER VALLY	.4779E-05
11	5	INDIAN POINT	.4684E-05
12	11	PEACH BOTTOM	.4677E-05
13	6	LIMERICK	.4451E-05
14	29	OCONEE	.4378E-05
15	17	THREE MI. ISLAND	.4221E-05
16	41	CLINTON	.4042E-05
17	59	FORT CALHOUN	.4005E-05
18	3	HADDAM NECK	.3986E-05
19	47	LASALLE	.3941E-05
20	53	ARKANSAS	.3797E-05
21	52	ZION	.3364E-05
22	8	MILLSTONE	.3345E-05
23	18	VERMONT YANKEE	.3204E-05
24	16	SUSQUEHANNA	.2877E-05
25	28	NORTH ANNA	.2849E-05
26	61	LA CROSSE	.2721E-05
27	42	COOK 1 & 2	.2714E-05
28	35	VOGTLE	.2655E-05
29	27	MCGUIRE	.2597E-05
30	33	SUMMER	.2592E-05
31	15	SHOREHAM	.2550E-05
32	30	ROBINSON	.2395E-05
33	48	PALISADES 1	.2327E-05
34	24	CATAWBA	.2285E-05
35	62	MONTICELLO	.1938E-05
36	63	PRAIRIE ISLAND	.1836E-05
37	13	SALEM	.1802E-05
38	43	DAVIS BESSE 1	.1802E-05
39	4	HOPE CREEK	.1757E-05
40	21	BROWNS FERRY	.1672E-05
41	50	POINT BEACH	.1658E-05
42	32	SHEARON HARRIS	.1634E-05
43	40	BYRON 1 & 2	.1383E-05
44	23	CALVERT CLIFFS	.1370E-05
45	10	OYSTER CREEK	.1367E-05
46	44	DRESDEN 2&3	.1362E-05
47	39	BRAIDWOOD	.1286E-05
48	46	KEWAUNEE	.1269E-05
49	45	FERMI 2	.1208E-05
50	2	GINNA	.1190E-05
51	49	PERRY	.1178E-05
52	38	BIG ROCK POINT	.1119E-05
53	26	HATCH	.1116E-05
54	34	SURRY	.1034E-05
55	9	NINE MILE POINT	.1002E-05
56	1	FITZPATRICK	.9798E-06
57	54	CALLAWAY	.8241E-06
58	25	FARLEY	.7470E-06
59	51	QUAD CITIES	.6566E-06
60	69	WOLF CREEK	.6046E-06
61	64	RIVER BEND	.5831E-06
62	68	WATERFORD	.5342E-06
63	60	GRAND GULF	.5035E-06
64	58	DUANE ARNOLD	.4553E-06
65	57	CRYSTAL RIVER	.4512E-06
66	67	TURKEY POINT	.3837E-06
67	55	COMANCHE PEAK	.3238E-06
68	66	ST. LUCIE	.3190E-06
69	65	SOUTH TEXAS	.2909E-06

Column (1) is for the site numbers for Fig. 3.1.3
Column (2) is for the site numbers as ordered in Vol. I
Column (3) is the median hazard value of 0.6g

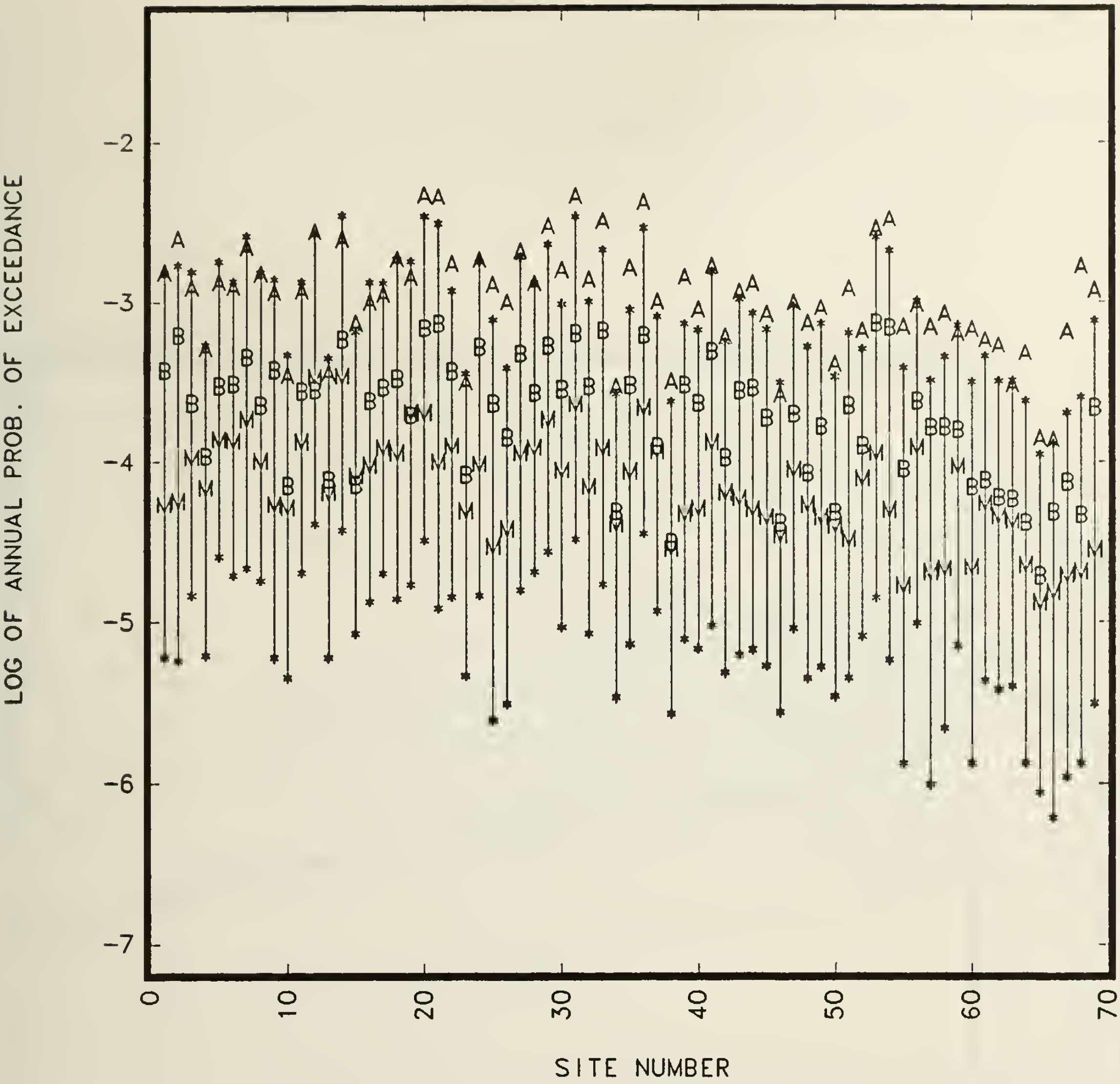


Figure 3.1.2a Plot of the log of the annual probability of exceeding 0.2g for all the sites in Vols. II-V. The plot symbols are: A=arithmetic mean, M=median (50th percentile), (*) for the 15th and 85th percentiles and B=best estimate. The sites are ordered by Volume. The key is given in Table 3.1.1 and cross referenced in Table 3.1.2.

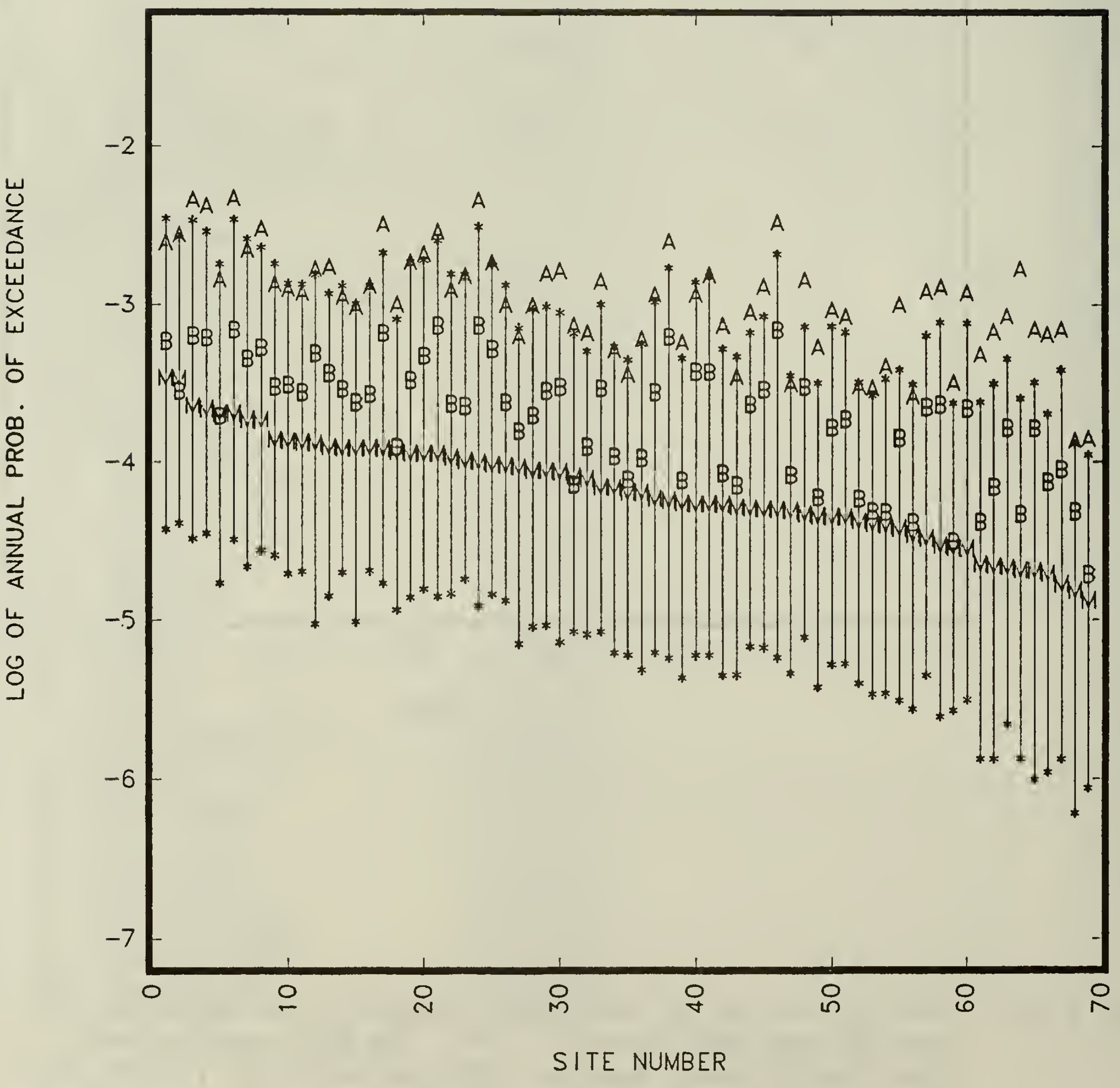


Figure 3.1.2b Same as Fig. 3.1.2a except the sites have been ordered by median probability of exceeding 0.2g. The ordering is given in Table 3.1.2 and cross referenced in Table 3.1.1.

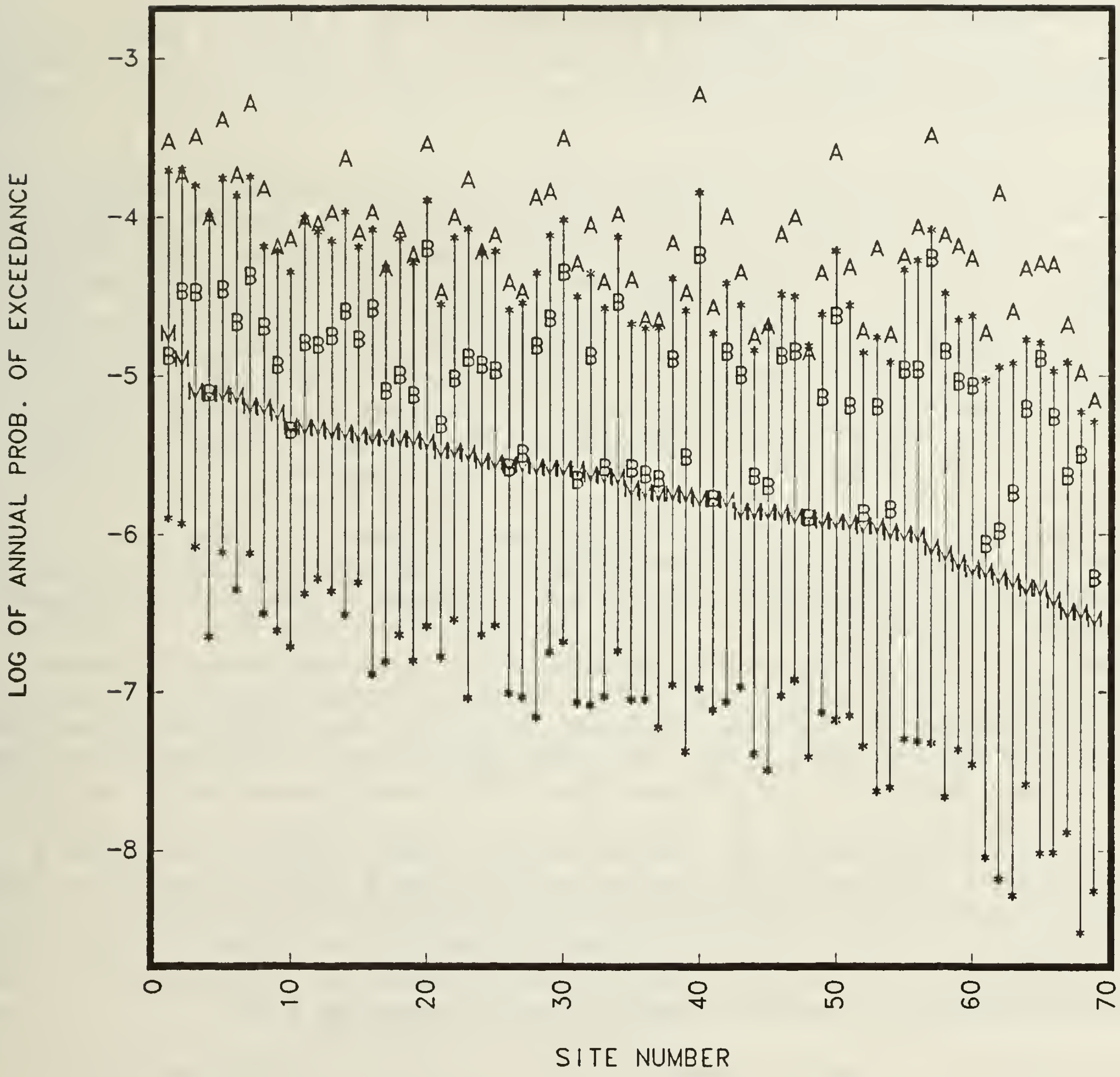


Figure 3.1.3 Plot of the log of the annual probability of exceeding 0.6g for all of the sites in Vols. II-V. The sites have been ordered by the median probability of exceeding 0.6g. The plot symbols are: M=median, A=arithmetic mean, (*)=15th and 85th percentiles and B=best estimate. The ordering is given in Table 3.1.3.

3.2 Regional Comparisons (PGA)

The median probability of exceedance of 0.2 g PGA for the sample of 69 sites across the EUS, shown in Fig. 3.1.2a, does not display any obvious characteristics that might correlate with the regional location of the sites. However, the grouping of sites used in Fig. 3.1.2a is not quite regional as explained in Vol. I, and in addition any such regional correlation could very well be obscured by the local site correction used in our analysis (see Section 2).

There are several natural groupings of the sites that might be interesting to compare. For example, it is interesting to compare the hazard at sites in New England to sites located either near the New Madrid region or the Charleston region. In making this comparison, we selected only rock sites. Because the Seabrook site has the highest median CPHC for PGA of the rock sites, we selected it and three other sites in New England relatively close to the Seabrook site. For the comparison between the Charleston and New Madrid areas, we considered it important to have the sites located approximately the same distance from either the New Madrid source region or the Charleston source region. In addition, our criterion of having rock sites for the comparison limited the number of sites. It should be noted, as can be seen by examining the various S-Experts' maps given in Appendix B, that there is a large variation in how the New Madrid and Charleston source zones are defined between the various S-Experts. Thus it is extremely difficult to define a meaningful distance metric to select the sites for comparison. We did not attempt to factor these complex considerations into our selection process in a rigorous way. Table 3.2.1 lists the sites we selected as best fitting our requirements and in addition to the New England sites, the three sites "near" Charleston and the three sites "near" New Madrid, we also selected three rock sites approximately mid-way between Charleston and the New Madrid region.

In Fig. 3.2.1 we plotted the location of the sites listed in Table 3.2.1 (indicated by the symbols X), the median PGA with a 10,000 year return period and the location of the Charleston (C) and New Madrid (NM) historic earthquakes. In Fig. 3.2.2 we plotted for each of the sites in Table 3.2.1 the median (M), best estimate (B), arithmetic mean (A), and the 15th and 85th percentile value (*) annual probabilities of exceeding 0.2g.

It is difficult to make statements about the relative difference between the New England region and sites "near" either the Charleston or New Madrid regions because if we examined locations closer to either of these two source zones, the seismic hazard would significantly increase over the values shown in Fig. 3.2.1 whereas it is unlikely that a site in New England would have a median seismic hazard level significantly higher than the level at the Seabrook site.

We see from Fig. 3.2.2 that the hazard estimates for the three sites near the New Madrid region (site numbers 8, 9 and 10 in Fig. 3.2.2) are more uncertain than the estimates at the other sites. The make-up of the earthquakes contributing to the hazard are different for the three groupings of sites and

the range of size of possible earthquake motion at those sites is larger than at the other 7 sites considered in Fig. 3.2.2. The relative contribution of various earthquakes for each site is discussed in the appropriate section in Vols. II-V and plotted in Fig. 2.SN.4 for each site (where SN is the site number). Fig. 3.2.3 is a plot of the estimated 10,000 year return period PGA based on the BEHC estimator and including only earthquakes 6.5 and larger for each of the sites listed in Table 3.2.1. We see that the three sites near New Madrid are much higher than either for the sites near Charleston or between Charleston and New Madrid. The BE PGA hazard in New England is the smallest in this figure. From this we can infer that the hazard near New Madrid is primarily from very large earthquakes whereas for the Charleston area smaller local earthquakes are more important and thus level of hazard from large earthquakes is smaller for sites near Charleston than for sites around New Madrid region but larger than for sites in New England. To further illustrate this point and show that Figs. 3.2.4 agree with the above discussion we plotted the relative contribution to the BEHC for PGA only from earthquakes within 4 magnitude ranges for the Arkansas site (near New Madrid), the Catawba site (near Charleston), the Seabrook site (New England), and the Watts Bar site (between NM and C). The Figs. 3.2.4 were previously shown in Figs. 3.2.4a, b, c, d in Vols. II-V.

In Fig. 3.2.5 we plot the relative locations of all the sites in this study and the median PGA with a 10,000 year return period. The rock sites are denoted by R, the deep soil sites by D and the shallower soil sites by S.

Fig. 3.2.5 indicates that, among those sites close to each other and therefore within similar seismotectonic environments, the 10,000 year return period PGA at shallow sites is higher than at rock sites, as expected from a prior discussion on the effect of correction for soil site conditions in Section 2.2. As indicated earlier, it is difficult to see any obvious trend in the effect of site correction, and if we only based our conclusions on Fig. 3.2.6 which shows the ratios of probabilities of exceedance of 0.2g between the shallow soil case and the rock case at the 12 sites, we would erroneously conclude that it is quite erratic and unpredictable.

However, it is easier to understand the behavior of the results when the parameter of interest is the ground motion parameter itself (i.e., the PGA or PSRV) rather than the probabilities of exceedance.

Let us first examine the ratios, r(p), of PGA between the shallow soil $a_s(p)$ to the rock case $a_r(p)$ for three different but fixed probabilities of exceedance (p) equal to 10^{-3}, 10^{-4} and 10^{-5}. r(p) is defined by:

$$r(p) = \frac{a_s(p)}{a_r(p)}$$

The values of $a_s(p)$ and $a_r(p)$ reported in Table 3.2.3 (Table 3.1.1 of Vol. VIII) are taken from the Fig. 2.SN.4 of Vol. VIII for each of the 12 sites in Table 3.2.3.

Recall that there are two types of site corrections being applied in this analysis (see Vol. I Section 3.7).

- One type of correction is the simple correction advocated by G-Expert 5, for which the median correction factor shallow soil/rock is approximately equal to 0.73 (see left side of Fig. 3.10 in Vol. I) regardless of the specific shallow site category.

- The other type of correction, advocated by the other 4 G-Experts, is the categorized correction for which the ratios (shallow/rock) depend on the soil category (see left sides of Figs. 3.12 and 3.13 of Vol. I) and are equal to:

  Sand-1/Rock: r=1.65
  Till-1/Rock: r=1.55
  Till-2/Rock: r=1.38

Thus if the only ground motion input used were that of G-Expert 5, we would expect the average correction factor r(p) to be always approximately 0.73.

Furthermore, if G-Expert 5's input were not used, we would expect the average ratio shallow/rock to be 1.65 when the shallow soil is in category Sand-1, 1.55 if it is in category Till-1, and 1.38 if it is in category Till-2.

Since the results presented here used input from all the G-Experts in a proportion approximately of 1/5 weight for each of them, we would expect, on the average, the ratios r(p) to be equal to:

$(.73)(.20) + (1.65)(.80) = 1.47$ for Sand-1/Rock
$(.73)(.20) + (1.55)(.80) = 1.39$ for Till-1/Rock
$(.73)(.20) + (1.38)(.80) = 1.25$ for Till-2/Rock

Column (7) of Table 3.2.3 gives for each of the 12 sites of Table 1.1 the expected approximate ratio if G-Expert 5 were not used, column (6) shows the expected ratio if only G-Expert 5 were used, column (5) gives the expected approximate ratio if all G-Experts were weighted equally, and the next column (4) gives the average of the ratios shallow/rock given in columns (1), (2) and (3). Columns (1), (2) and (3) give the r(p) values for the probabilities of exceedance 10^{-3}, 10^{-4} and 10^{-5}.

Table 3.2.3 shows clearly that the effective correction factors (column (4)), which are obtained as an average of correction factors for three given probabilities of exceedance, are in general very close to the approximate values one would expect if the ground motion experts choices of correction were weighted equally (compare columns (4) and (5) in Table 3.2.3).

The deviation from the value in column (5) is due to the complex interaction between ground motion models and seismicity zones, seismicity parameters and the fact that the correction factor is not deterministic but is defined by a probability distribution. Depending on all those factors the impact will be that the correction advocated by G-Expert 5 will have more or less weight, relative to the other 4 experts. For Oconee, the combination of the above

mentioned interactions leads to an impact of G-Expert 5 greater than the equal weight case. For the other sites, but Three Mile Island and North Anna, the effect is reversed and the opinion of G-Expert 5 appears to be more diluted than in the equal weight case.

For Three Mile Island and North Anna neither group (i.e., with or without G-Expert 5) seems to dominate.

The case of Arkansas, Callaway and Duane Arnold requires additional scrutiny. For those three sites, Table 3.2.3 shows that the effective amplification factors (column (4)) obtained in our simulation are close to the case when Expert 5's model is not used (compare column (4) with column (7)).

This phenomenon seems extreme and can be explained as follows, (remembering that we are comparing median hazard curves for rock and for soil):

- For the rock case, the contribution to the hazard comes from distant large earthquakes. Figure 3.4 of Vol. I shows that in that range, G-Expert 5's ground motion model (number 3 on Fig. 3.4-Vol. I) is much higher than the rest of the models. Thus, the resultant median value is more representative of the other four ground motion models.

- For the shallow soil case, the large, distant earthquakes are also dominant, and G-Expert 5's model falls within the cluster of other models, thus, the median will be representative of all the models, and in particular again close to the median without Expert 5.

The result is that the final ratio of PGA between shallow and rock cases for these three sites is close to the case when only the categorized correction is used (i.e., the correction recommended by all but G-Expert 5).

Prior to drawing some conclusions, let us define the meaning of the term "correction" of the hazard curve. Let us assume that the hazard curve for a rock site is known, and one needs to have an estimate of the hazard at the same location but for a shallow soil condition. If one assumes the amplification from rock to soil to be a constant multiplicative value (say r_c), then one would generate rigorously the soil hazard curve by taking each point of the rock hazard curve, say acceleration a_R for a probability of exceedance h, and derive the corresponding point, a_S, for the same probability of exceedance h, of the soil hazard curve such that

$$a_S = a_R \cdot r_c \qquad \text{at constant h.}$$

Although this operation is correct for a constant r_c as indicated above, it would not be correct to perform it when a combination of correction types are used as in our study where the final effect is in between the two types of corrections as indicated in Table 3.2.3, and the relative weight of each type of correction depends both on the dominant zonation effects and on the dominant ground motion models.

However, Table 3.2.3 shows that constructing a soil hazard curve by first starting from our rock hazard curves and applying an average correction factor would lead to an estimated soil hazard curve close to the hazard curve estimated by our full method described in Vol. I and Section 2.2 of this volume.

Table 3.2.3 shows that the error could be negligible in some cases, and at most, for the 12 sites considered here, the error would have been 13% (for Callaway). In all 12 cases but one (i.e., Oconee), the error would have been an underestimation (it would have been overestimated by approximately 3% at Oconee).

At the present time, we have not been able to derive any simple correlation between this effective amplification factor (column (4) of Table 3.2.3) and the zonation characteristics, location, soil conditions, or any other parameters specific to any given site, thus making impossible the rigorous transformation of our rock hazard curves into soil hazard curves in a simple way.

And finally, one needs to caution the reader in extending the above conclusions to the probability of exceedance space. In spite of the remarkable stability of the correction factors shown in Table 3.2.3, Fig. 3.2.6 shows a quite different effect. Figure 3.2.6 shows the ratios as a function of both the average slopes of the hazard curves (soil and rock hazard curves) and the average amplification from rock to soil. If all sites exhibited exactly the same rock hazard curves, then Fig. 3.2.6 would be an exact representation of column (4) of Table 3.2.3. However, the slopes of those hazard curves are not exactly the same as 0.2g, thus Fig. 3.2.6 shows some deviation from column (4) of Table 3.2.3. The general shape of Fig. 3.2.6 is representative of the overall process and can be considered as some sort of a signature.

If some elements of the zonation, seismicity or ground motion models were to be changed, Fig. 3.2.6 would change. In a sensitivity test, we removed ground motion Experts' 5 input and found that Fig. 3.2.6 was slightly changed but its general shape and level were preserved.

We feel confident that the effects shown in Table 3.2.3 and Fig. 3.2.6 are realistic representations of the physical effects given our assumptions on the site correction methods, and not due to some unexpected parasitic software or numerical problems such as the choice of number of simulation, for we have performed numerous tests in previous studies to validate our operating parameters (Bernreuter et al., 1985).

Table 3.2.1

Rock Sites Selected for the Comparison Between the Hazard for Sites Located in New England, near Charleston, near New Madrid, and Half-Way Between New Madrid and Charleston

Location	Plot #	Site Name	Median PGA (g) with a 10,000 Year Return Period	Vary Approximate Distance (km) NM	C
New England	1	Maine Yankee	0.253	--	--
	2	Millstone	0.197	--	--
	3	Seabrook	0.311	--	--
	4	Vermont Yankee	0.205	--	--
Near Charleston	5	Catawba	0.193	--	275
	6	McGuire	0.204	--	300
	7	Oconee	0.244	--	300
New Madrid	8	Arkansas	0.205	300	--
	9	Browns Ferry	0.195	250	--
	10	Callaway	0.151	300	--
Between NM & C	11	Bellefonte	0.256	350	600
	12	Sequoyah	0.267	400	550
	13	Watts Bar	0.267	425	550

TABLE 3.2.2

LIST OF SITES WITH SOME STRUCTURES FOUNDED ON ROCK AND SOME ON SHALLOW SOIL

Section Number	Site Name	Soil Category in Vols. II-V	Results in	Secondary Soil Category	Ratios Soil/Rock(*)		Plot Symbol
					Average Ratio of PGAs at $10^{-3}, 10^{-4}, 10^{-5}$ Probability	CPHCs at 0.3g	
1	Nine Mile Point	Rock	Vol. II 2.9	Sand-1	1.58	4.3	1
2	Susquehanna	Rock	Vol. II 2.16	Till-2	1.30	2.1	2
3	Three Mile Island	Rock	Vol. II 2.17	Sand-1	1.47	2.4	3
4	Browns Ferry	Rock	Vol. III 2.2	Sand-1	1.63	5.1	4
5	Catawba	Rock	Vol. III 2.5	Sand-1	1.58	3.6	5
6	Farley	Rock	Vol. III 2.6	Sand-1	1.53	3.0	6

TABLE 3.2.2
(CONTINUED)

LIST OF SITES WITH SOME STRUCTURES FOUNDED ON ROCK AND SOME ON SHALLOW SOIL

Section Number	Site Name	Soil Category in Vols. II-V	Results in	Secondary Soil Category	Ratios Soil/Rock(*)		Plot Symbol
					Average Ratio of PGAs at 10^{-3}, 10^{-4}, 10^{-5} Probability	CPHCs at 0.3g	
7	North Anna	Rock	Vol. III 2.9	Sand-1	1.51	3.0	7
8	Oconee	Rock	Vol. III 2.10	Sand-1	1.43	2.7	8
9	Summer	Rock	Vol. III 2.14	Sand-1	1.57	3.6	9
10	Arkansas	Rock	Vol. V 2.1	Till-1	1.51	2.5	A
11	Callaway	Rock	Vol. V 2.2	Sand-1	1.69	5.1	B
12	Duane Arnold	Rock	Vol. V 2.6	Till-1	1.50	3.1	C

(*) Note: For details on the calculations of the ratios, see Section 3.1.

TABLE 3.2.3

RATIOS OF PGA VALUES BETWEEN SHALLOW AND ROCK CONDITIONS FOR FIXED VALUES OF THE HAZARD

Site	Soil Category	Ratio Shallow/Rock 10^{-3} (1)	10^{-4} (2)	10^{-5} (3)	Avg. (4)	All Equal Weight (5)	Only G5* (6)	W/O G5** (7)
1 Nine Mile Point	Sand-1	1.57	1.58	1.59	1.58	1.47	0.73	1.65
2 Susquehanna	Till-2	1.30	1.30	1.30	1.30	1.25	0.73	1.38
3 Three Mile Island	Sand-1	1.50	1.47	1.44	1.47	1.47	0.73	1.65
4 Browns Ferry	Sand-1	1.56	1.66	1.68	1.63	1.47	0.73	1.65
5 Catawba	Sand-1	1.59	1.58	1.55	1.57	1.47	0.73	1.65
6 Farley	Sand-1	N/A	1.56	1.49	1.53	1.47	0.73	1.65
7 North Anna	Sand-1	1.51	1.50	1.51	1.51	1.47	0.73	1.65
8 Oconee	Sand-1	1.37	1.44	1.47	1.43	1.47	0.73	1.65
9 Summer	Sand-1	1.47	1.62	1.61	1.57	1.47	0.73	1.65
10 Arkansas	Till-1	1.51	1.50	1.50	1.50	1.39	0.73	1.55
11 Callaway	Sand-1	1.65	1.70	1.72	1.69	1.47	0.73	1.65
12 Duane Arnold	Till-1	N/A	1.50	1.50	1.50	1.39	0.73	1.55

* Ratio of PGA shallow/rock given by G-Expert 5 only
** Ratio of PGA shallow/rock given by G-Experts 1,2,3 and 4 only

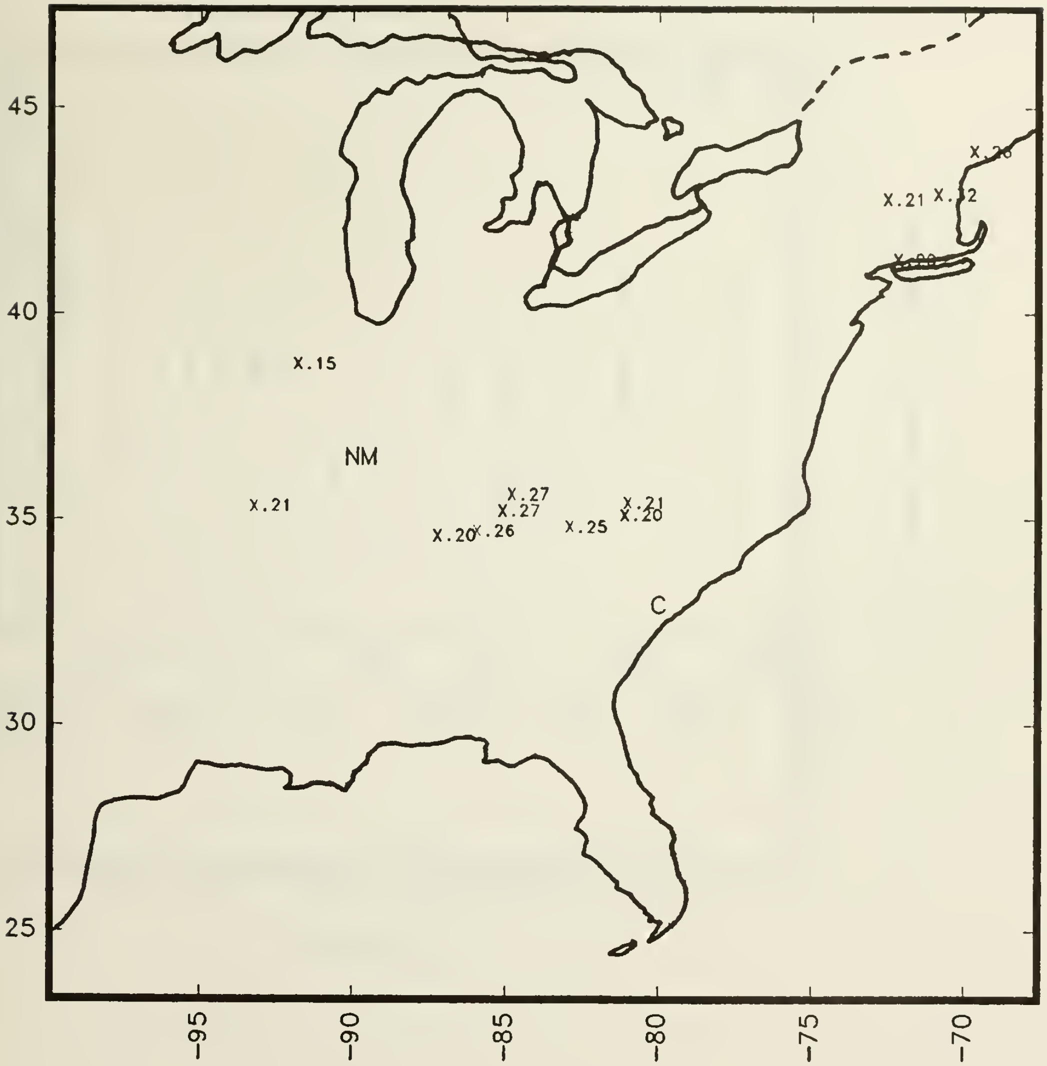


Figure 3.2.1 The location of the sites listed in Table 3.2.1 is shown by the symbol X relative to the historic New Madrid (NM) and Charleston (C) earthquakes. The 10,000 year return period PGA median g-values are also shown.

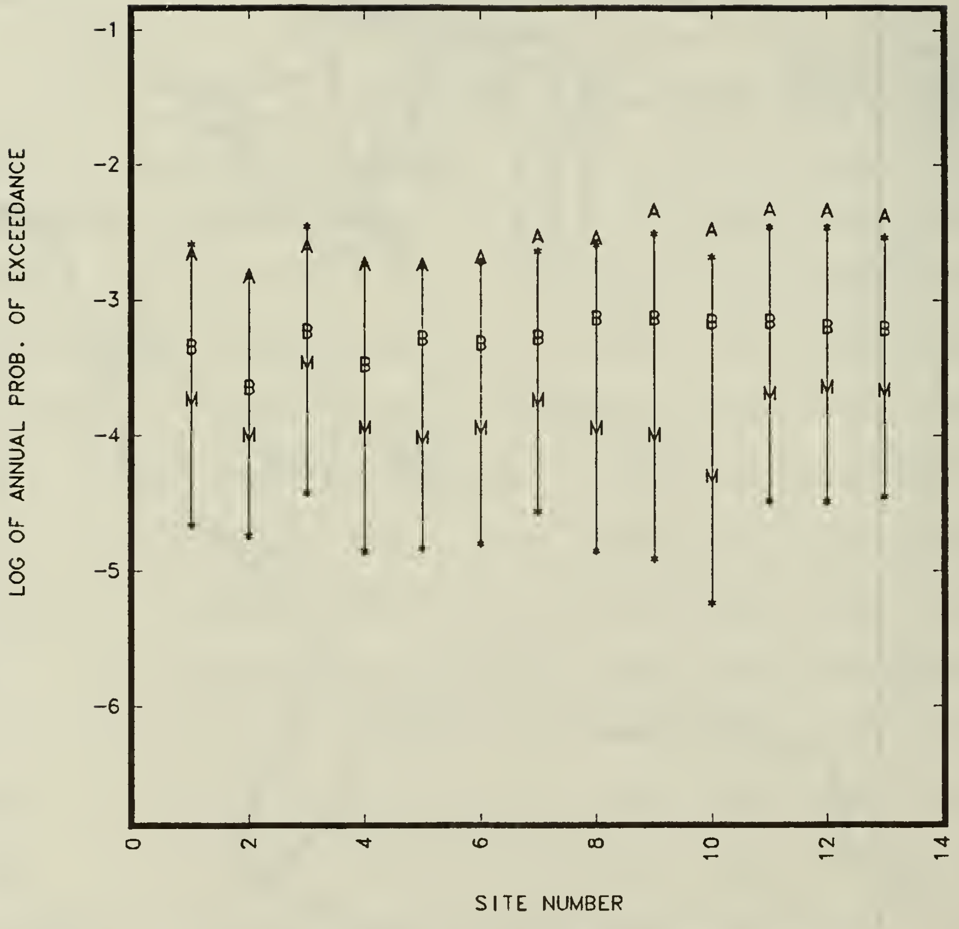


Figure 3.2.2 A plot of the log of the annual probability of exceeding 0.2g for each of the sites listed in Table 3.2.1. The site number is given in Table 3.2.1. The plot symbols are: M=median, A=arithmetic mean, (*)=15th and 85th percentiles and B=best estimate.

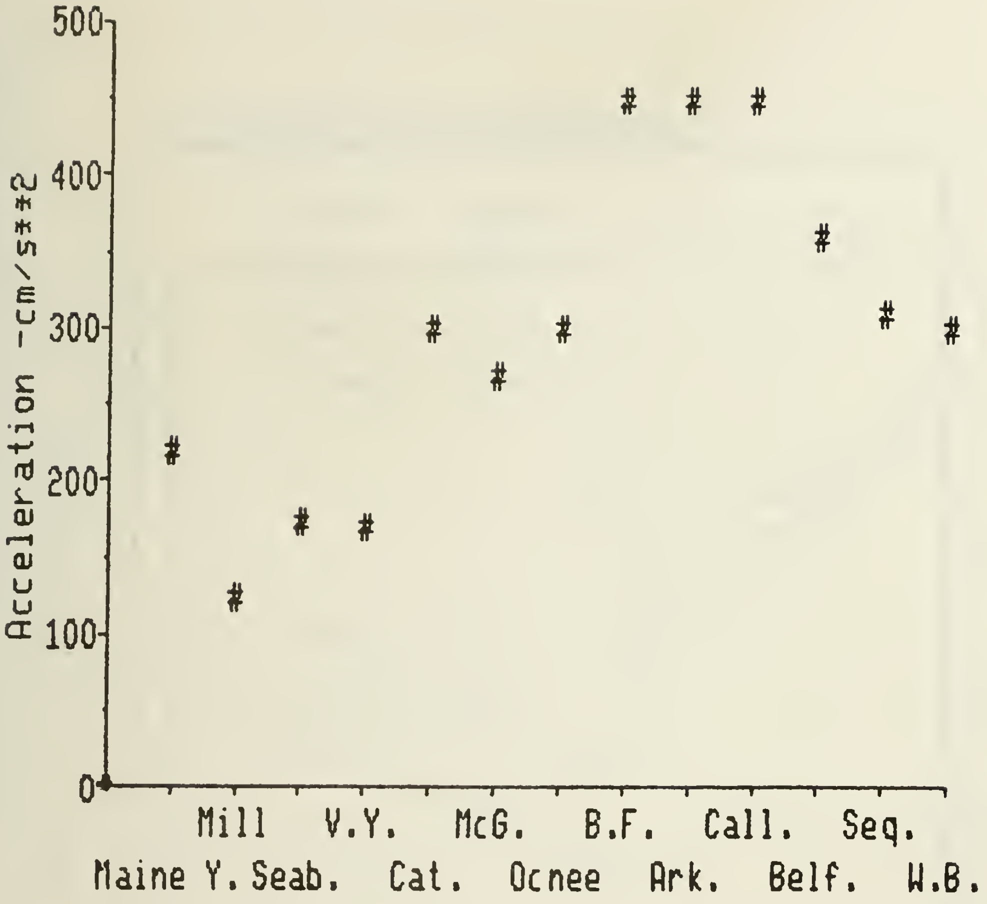


Figure 3.2.3 A plot of the estimated 10,000 year return period PGA only including large earthquakes of magnitude 6.5 and greater based on the BEHCs for each site listed in Table 3.2.1.

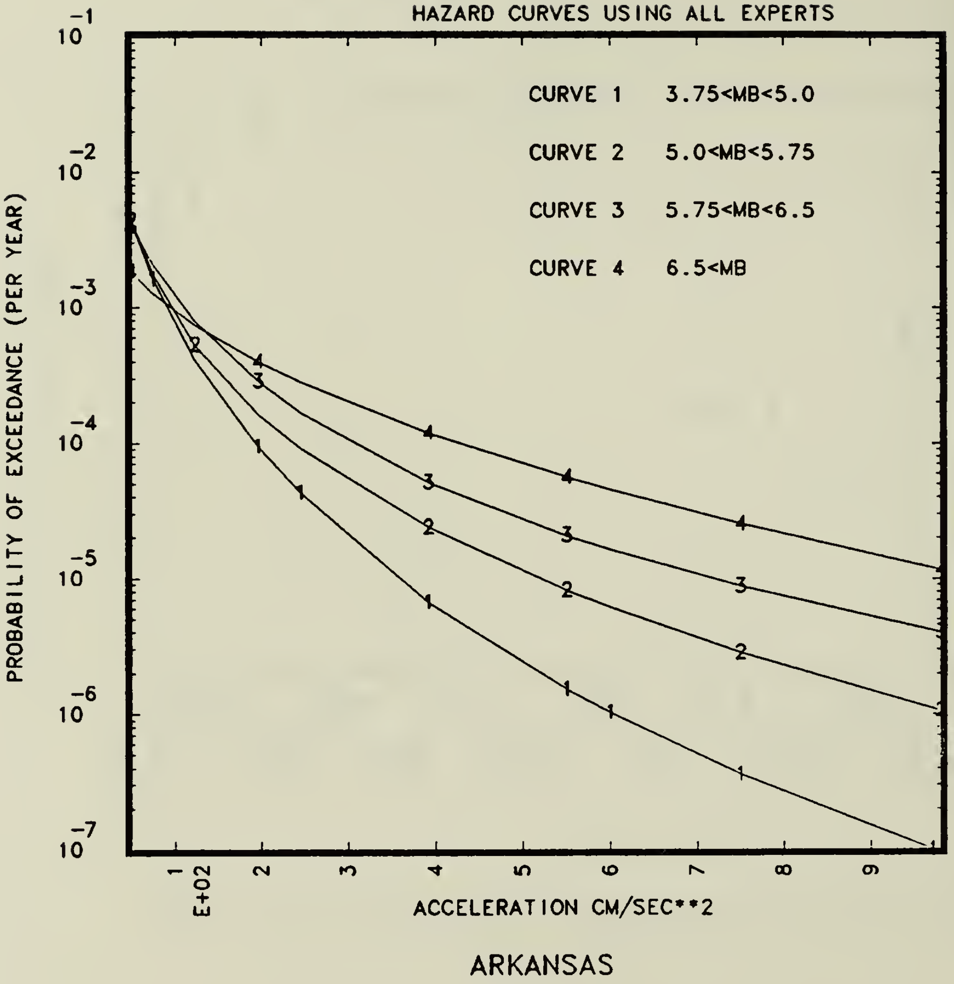


Figure 3.2.4a BEHCs which include only the contribution to the PGA hazard from earthquakes within the indicated magnitude range for the Arkansas site (near the New Madrid area).

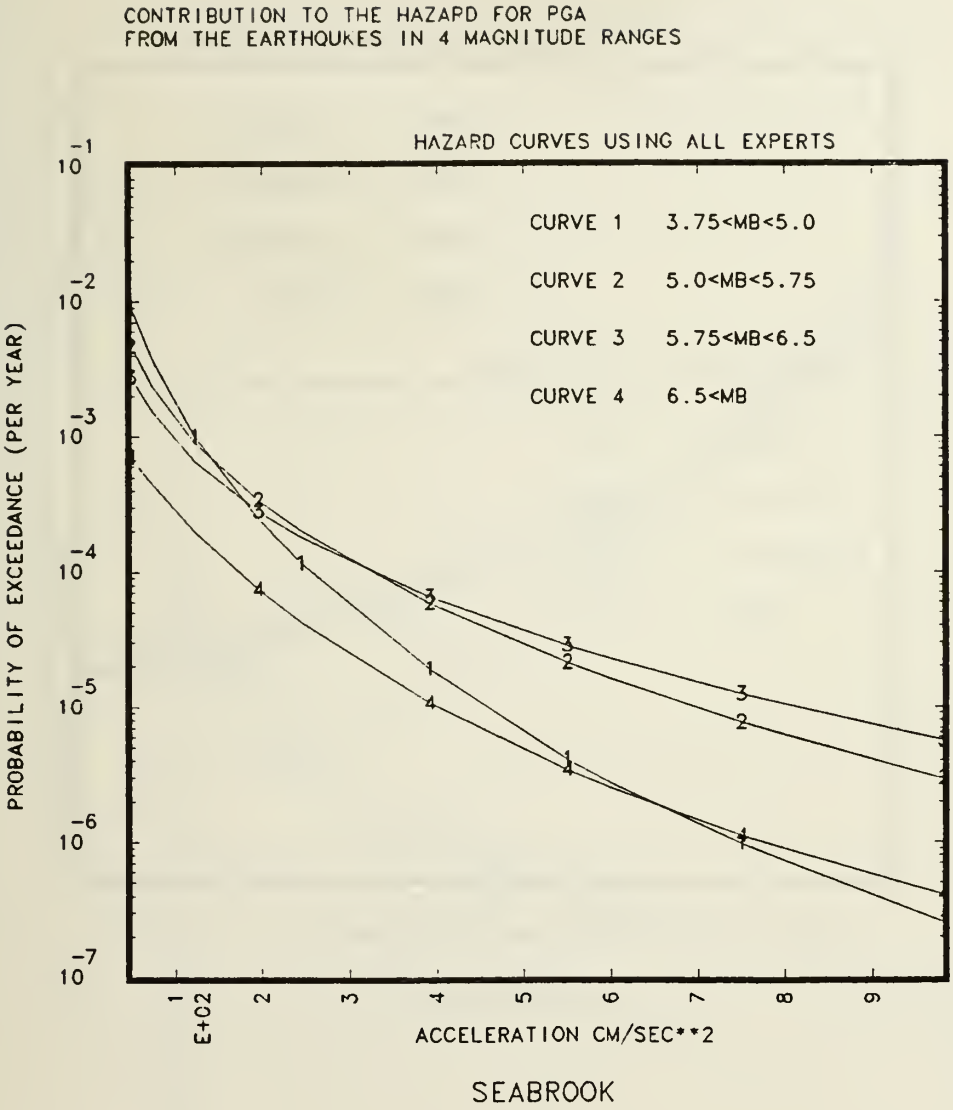


Figure 3.2.4b BEHCs which include only the contribution to the PGA hazard from earthquakes within the indicated magnitude range for the Seabrook site, in New England (far from either the New Madrid or the Charleston areas).

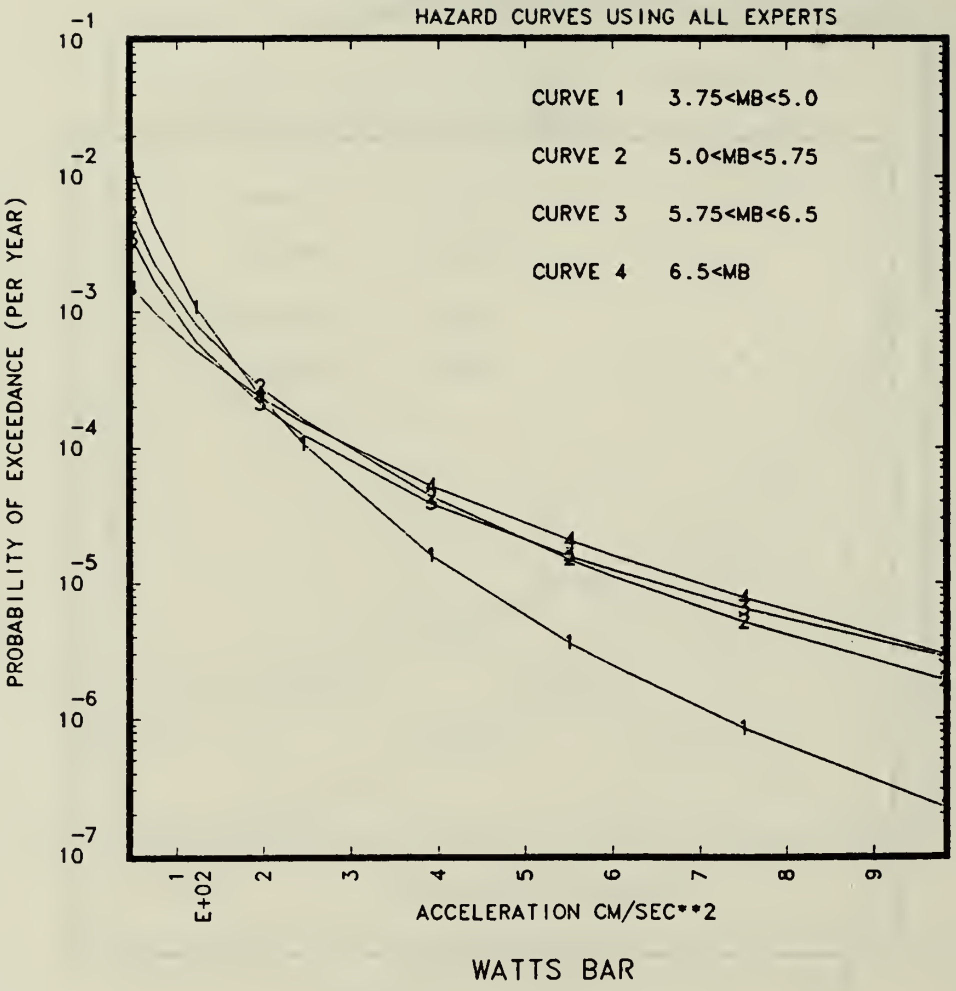


Figure 3.2.4c BEHCs which include only the contribution to the PGA hazard from earthquakes within the indicated magnitude range for the Watts Bar site (between the New Madrid and the Charleston areas).

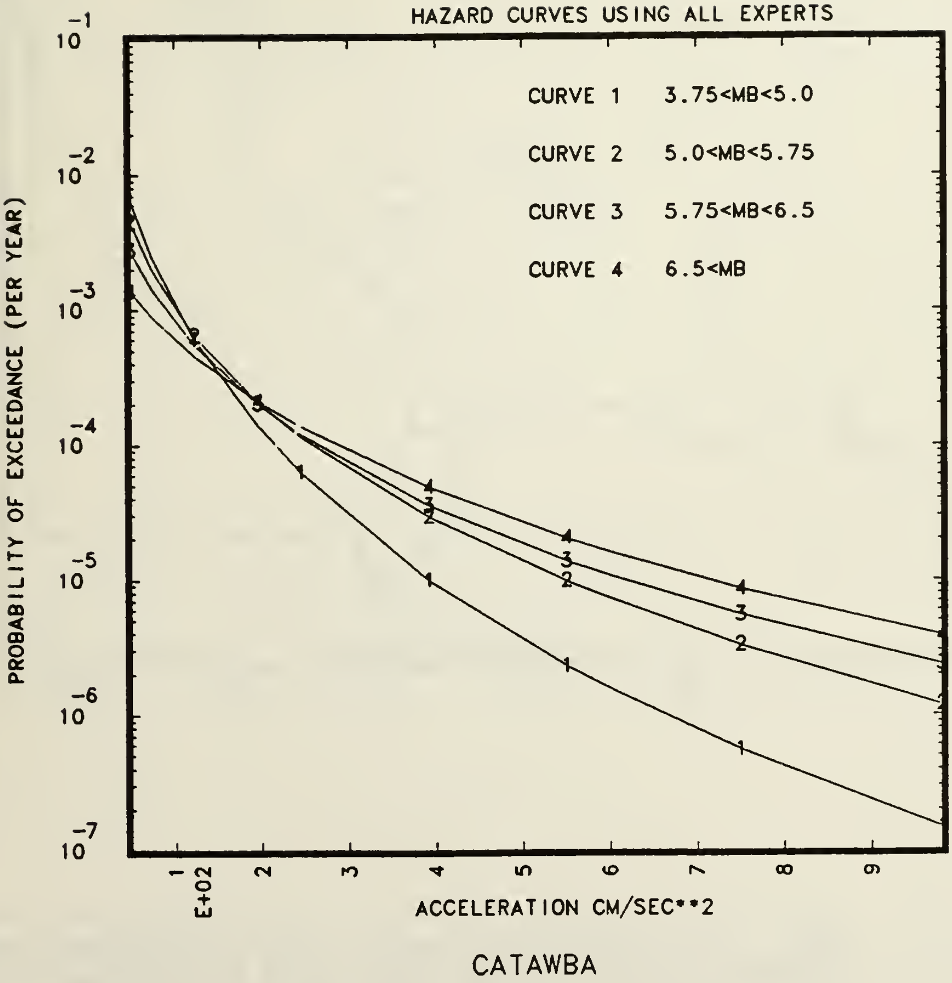


Figure 3.2.4d BEHCs which include only the contribution to the PGA hazard from earthquakes within the indicated magnitude range for the Catawba site near the Charleston area.

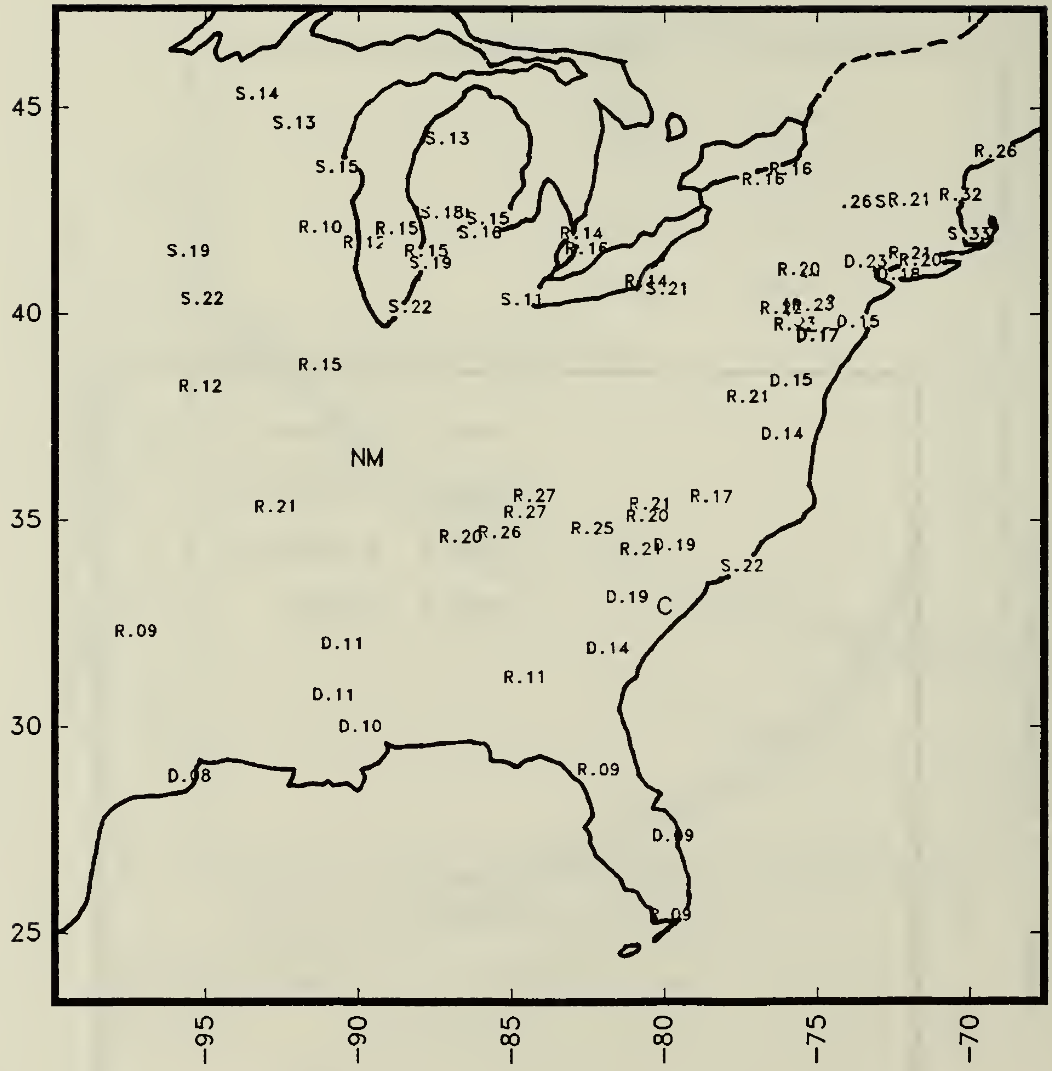


Figure 3.2.5 A plot of the relative location of all the sites in the study. The median PGA g-levels with a 10,000 year return periods are also plotted. Rock sites are denoted by "R", deep soil sites by "D" and shallow soil sites by "S". The relative location of the New Madrid (NM) and Charleston (C) earthquakes are also shown.

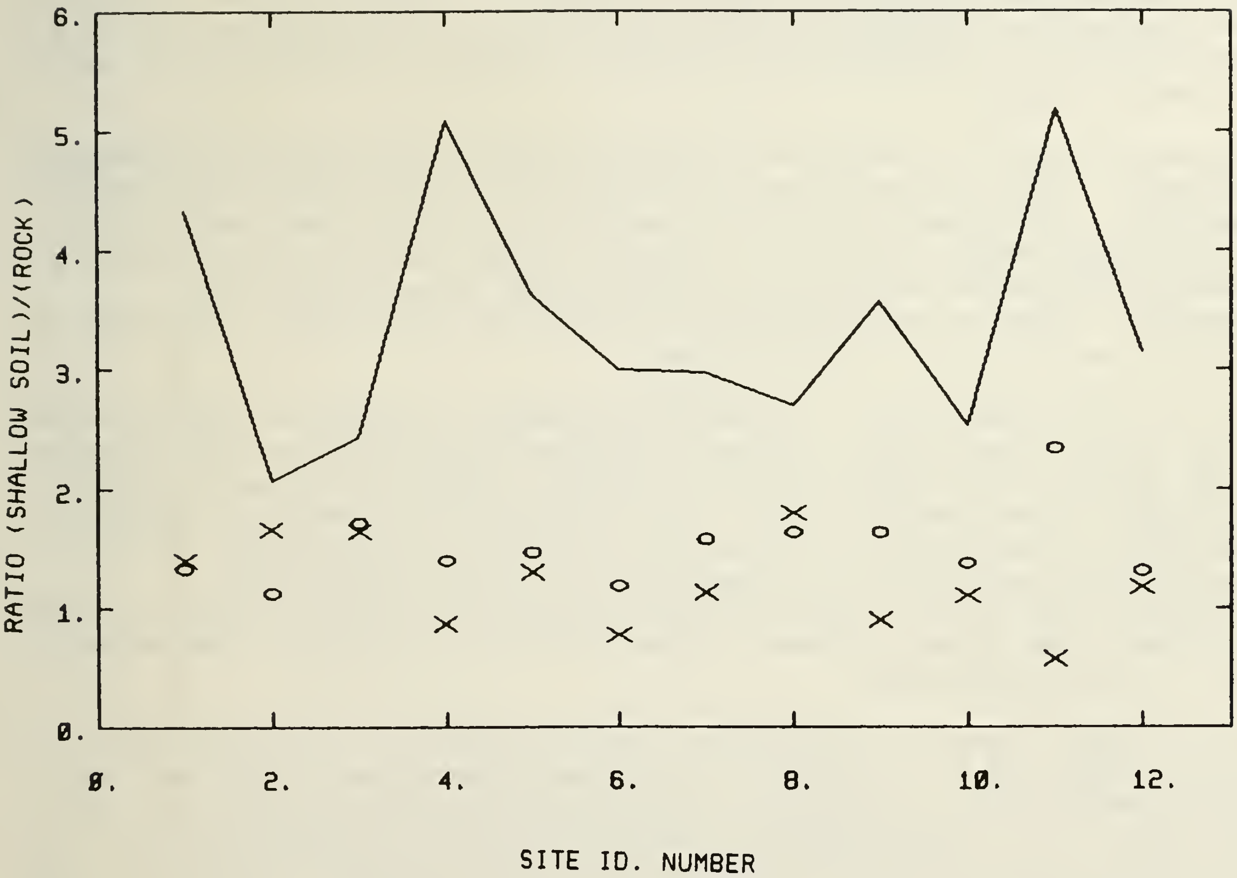


Figure 3.2.6 Plot of the ratio of the probability of exceeding 0.3g PGA for the median (line), 85th percentile (plot symbol, "O") and the arithmetic mean (plot symbol, "X") for the (shallow soil case)/(rock case). Site ID number is the same as the section number listed in Table 1.1.

3.3 Regional Spectral Comparisons

There are three elements which primarily control both the spectral shape and level. First, it is the choice of the GM model, here we are referring to the major differences between the RV-spectral models and either the Newmark-Hall type models or the intensity based models. See Figure 2.4.2. Secondly, the local soil conditions have an extremely important impact on both the spectral shape and level as discussed in Section 2.2. Finally, the regional seismicity can influence both the spectral shape and level. In the preceding sections we have examined the influence of factors (1) and (2) mentioned above. In this section we want to examine how the regional variation in seismicity influences the spectral shape.

The spectral level is sensitive to both the rate of occurrence and earthquake magnitude. The longer period part of the CPUHS is very strongly influenced by magnitude. Thus sites which are influenced by very large earthquakes, e.g., around the New Madrid region, will have more longer period energy than sites in New England where the local activity from smaller earthquakes is important. There is some influence of attenuation on the short period end of the spectrum, but it is relatively small.

This is illustrated in Fig. 3.3.1 where we compare the spectral shapes between a site where of very large earthquakes dominate the hazard as contrasted to a site at which the seismic hazard is governed primarily from smaller nearby earthquakes. The Limerick site is a rock site where the hazard is primarily from local seismicity and, as discussed in Section 3.2, the hazard at the Arkansas site (rock site) is primarily from the larger New Madrid earthquake. We see from Fig. 3.3.1 that the main difference in spectral shape is at the longer periods. There is some difference at the short period end but it is relatively small.

It is of some interest to compare the spectral shape for the four groups of sites in Table 3.2.1. In Fig. 3.3.2 we compare the median 10,000 year return period CPUHS between the Seabrook, Arkansas Catawba and Watts Bar sites (all rock sites). It is interesting to note that (for the four groupings of sites listed in Table 3.2.1), the New England group, the near Charleston group, and the half-way between group all have similar spectral shapes. The sites in the near New Madrid group have spectral shapes similar to the Arkansas site. Figure 3.2.4a, b, c, d shows that the relative contribution of very large earthquakes is much greater at the Arkansas site (typical for sites "near" New Madrid) than the other sites, thus there is relatively more long period energy in the Arkansas spectral shape.

To some extent, the regional difference between spectral shapes noted in Fig. 3.3.1 carries over to the case of soil sites. This is illustrated in Fig. 3.3.3 where we compare the CPUHS for the Clinton site (near New Madrid) to the CPUHS for the Yankee Rowe site (New England). We see from Fig. 3.3.3 that there is relatively more long period energy in the Clinton CPUHS than in the CPUHS for Yankee Rowe both shallow (i.e. Till-like 2) soil sites. This small relative difference is typical.

It is important to note that the regional differences observed in Figs. 3.3.1, 3.3.2, and 3.3.3 also hold (particularly relative to the median CPUHS) even if the low attenuation model selected by G-Expert 5 is not included. If reference is made to Fig. 2.3.6, we see that the spectral shape is similar for both the case when the low attenuation ground motion is included and the case when it is not included.

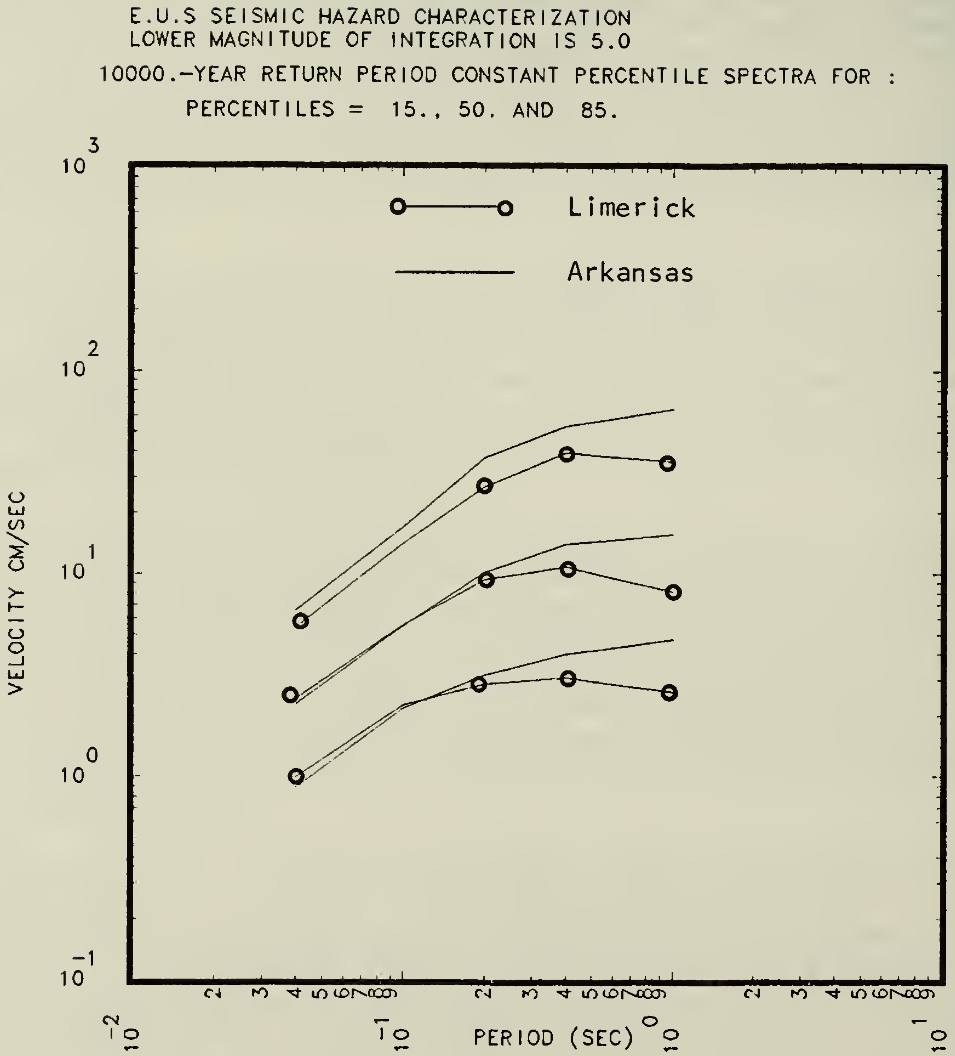


Figure 3.3.1 Comparison of the 10,000 year return period CPUHS between the Arkansas and Limerick sites (both rock sites).

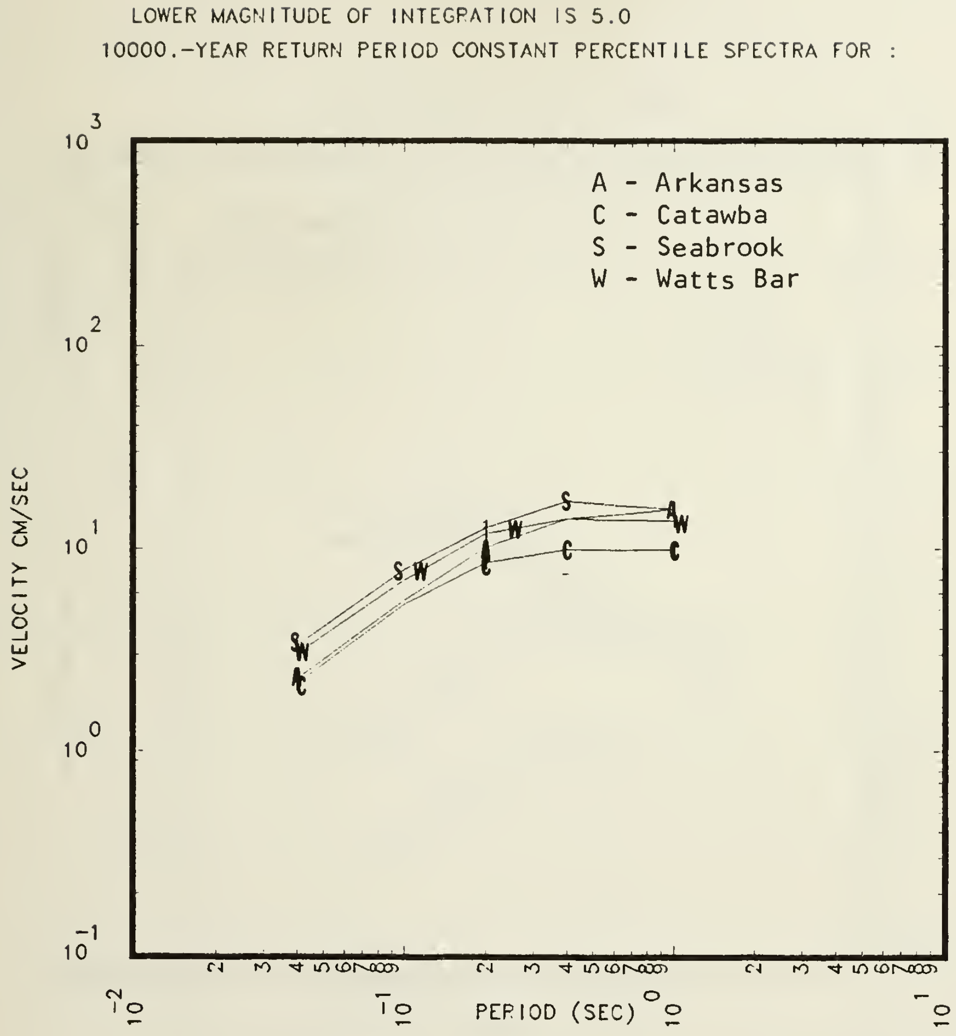


Figure 3.3.2 Comparison of the median 10,000 year return period CPUHS between the Seabrook, Catawba, Arkansas, and Watts Bar sites (all rock sites).

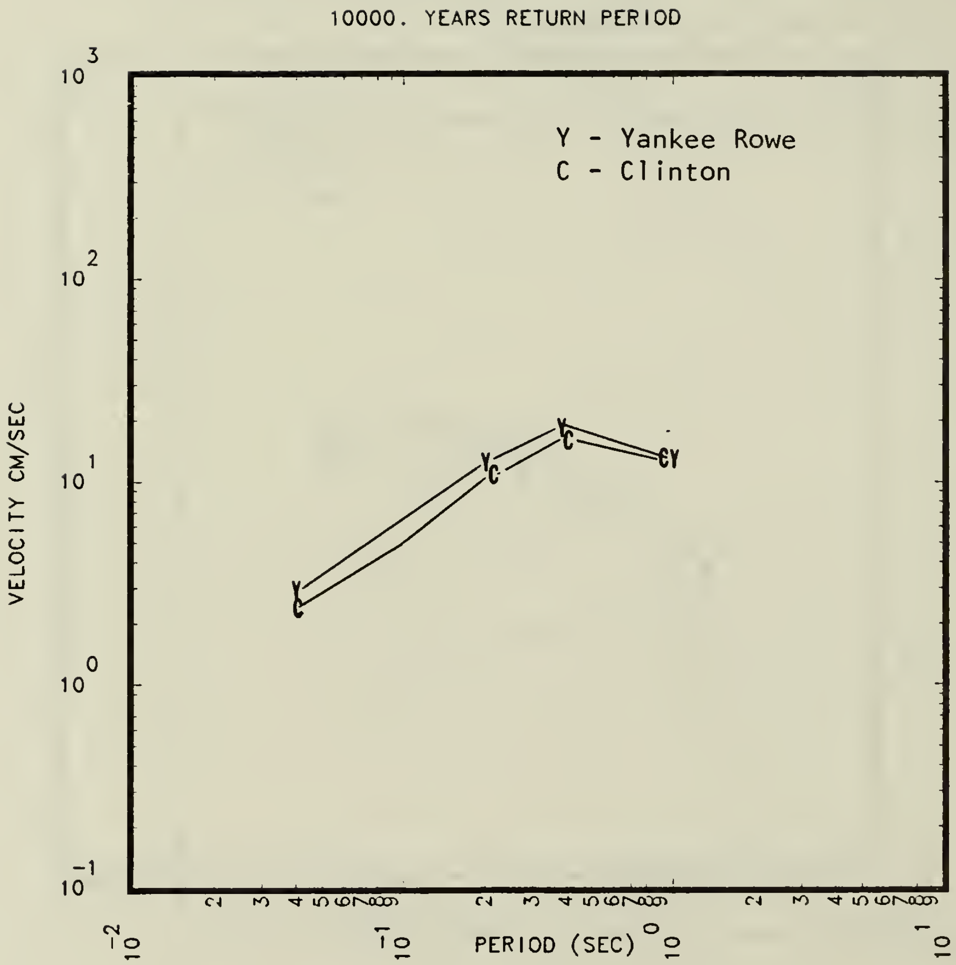


Figure 3.3.3 Comparison of the median 10,000 year return period CPUHS between two shallow soil sites (till-like 2). The Clinton site (near New Madrid) to the Yankee Rowe site (New England).

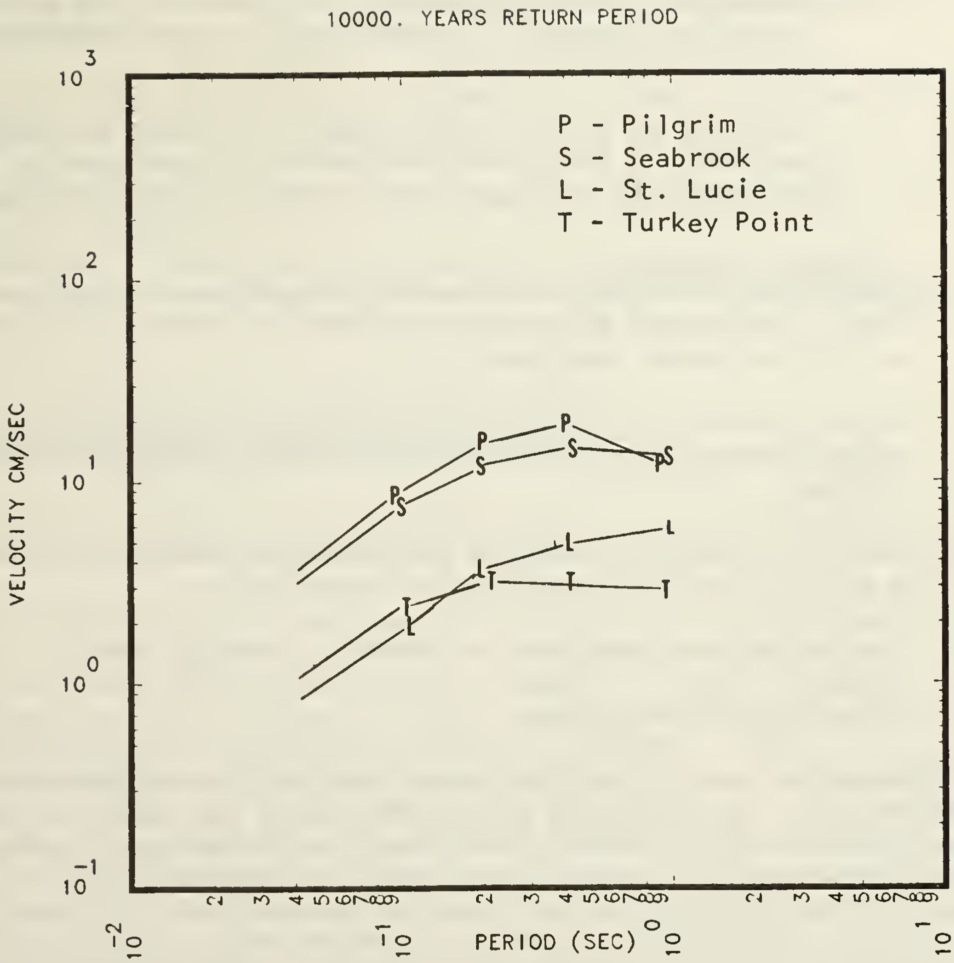


Figure 3.3.4 Comparison between the median 10000 year return period CPUHS for the sites with the lowest and highest median 10000 year CPUHS.

4. SUMMARY OF RESULTS AND CONCLUSIONS

The results of this study, including Bernreuter et al. (1985), provide the NRC with the tools for characterizing the seismicity of the EUS and for describing the hazard at any location within that region. These tools are:

a. A data base of estimates of the seismicity of the EUS and appropriate GM models, based on expert opinions', in the form of

   o a catalog of maps of zonation of the EUS along with estimates, including a measure of uncertainty in the estimates, of the seismicity of each zone.

   o a catalog of ground motion models including an assessment (weights) of their relative merits for propagating the motion at the source to motion at any location within the EUS.

b. A hazard methodology which uses the estimates in the data base (a) to develop an estimate of the seismic hazard at any location in the EUS. The seismic hazard is described in terms of a hazard curve and a uniform hazard spectrum.

c. A data base of estimates of the seismic hazard computed at the 69 sites with either operating nuclear power plants or plants seeking a license.

The data base for characterizing the seismicity of the EUS has been developed through an elicitation of the opinions of experts in:

o The geotectonic features and seismicity of the EUS.

o Ground motion modeling.

In using the data base it must be recognized that the results are based on information which was available to the experts at the time for the elicitation between 1983 and 1987. As additional events occur and more data become available these may be a basis for a change in opinion. Thus, it is recommended that the NRC consider updating the current data base on a periodic basis. This is particularly true of the ground motion models where there is considerable activity in development of new and improved ground motion models. Methods are also being developed for using the historical records of events to complement the opinions of experts about the seismicity. These methods have the potential for upgrading the seismicity data base.

The hazard methodology is based on a probabilistic model of the occurrence and distribution of magnitudes of earthquakes and the attenuation of the ground motion from a source to a site. It also includes modeling of local site effects. The methodology incorporates expert opinion to supplement the available data on zonation, seismicity and ground motion modeling.

The description of zonation, seismicity and choice of ground motion model and related parameters are assumed to be based on subjective opinions. The method assumes that these opinions are expressed in two ways:

a. A "best estimate" or most likely zonation, model or value of a parameter.

b. A collection of zonations or models with relative levels of confidence or a range of values for a parameter which is believed, by the expert, to represent the parameter with a high degree of confidence.

From these inputs the methodology can produce two types of estimates of the seismic hazard at a site:

o A single "best estimate" hazard curve or spectrum based on the best estimate inputs.

o A constant percentile hazard curve or spectrum which represents the uncertainty in the hazard as expressed by the

    a. Uncertainty of an individual expert.

    b. Variation in opinions among several experts.

When using these estimates, it is important that the user recognizes some characteristics and limitations of these results:

1. With respect to the "best estimate" hazard curve (spectrum), it should be recognized that this is a weighted average of the hazard curves based on the best estimate inputs of several experts. This is a single or point estimate of the hazard to which one associates no confidence that it represents the true hazard. Thus, it is not recommended that this curve (spectrum) be used as an absolute description of the seismic hazard at a site. This is particularly important since we found considerable variation in the best estimate hazards between experts associated with this project. Of course, it may be useful to consider point estimate hazard curves for a comparison of seismic hazard at different locations. However, even then we suggest that the total uncertainty, (due to the uncertainties and variations in opinions) in the hazard be recognized in making such comparisons. Other point estimates which take uncertainty into considerations are also outputs of the methodology. They are:

    o The median CPHCs.

    o The arithmetic mean hazard curve.

2. It should be recognized that the CPHCs, which represent the uncertainties associated with estimating the hazard based on

subjective opinions are not explicit hazard curves that are derived from a unique set of inputs. Neither are they a set of bounds to which can be associated a stated confidence, e.g. 90% confidence, that the true hazard curve is contained within the bounds. Rather, they are locus of the 15th and 85th percentile points, of the uncertainty distribution in the hazard, i.e. P(A>a), for each level a. Thus, an uncertainty statement, in the sense of uncertainty in the inputs, is applicable to the probability of the maximum PGA exceeding a specific level a. The same statement is not applicable over the entire range of a simultaneously.

3. Another issue which affects both the point estimate of the hazard and the description in the uncertainty in the hazard is the choice of weights for combining estimates over the collection of expert opinions. Our approach was to calculate the hazard (or the uncertainty distribution of the hazard) based on the inputs from each pair of seismicity and ground motion experts and then use self ratings as a basis for weights for combining the estimates over all possible pairs of experts. Appropriate methods for combining information from multiple sources, particularly information based on subjective opinions, is a complex subject. Several methods, based on rankings of experts or strictly mathematical weights, are available in the literature. Based on some limitations on the methods we could use and the ranking information we could elicit, we chose self ranking as the basis for the weights. However, we consider the issue of combining information, both from opinions as well as from both data based information and opinions as a topic requiring further investigation, particularly in light of the sensitivities of the results to certain combination of expert's input discussed in Section 2.3.

The detailed conclusions reached in the course of this study are discussed in the appropriate sections of the various volumes which comprise this report. The following is a summary of the most important ones:

(1) There is substantial uncertainty in the estimated hazard. The typical range in the value of the probability of exceedance between the 15th and 85th percentile curves for the PGA is on the order of 40 times, for low PGA; it is more than 100 at high PGA values. This translates into an approximate factor of 4 in ground motion for the 15th-85th range of values in the PGA given a fixed return period, and similarly an approximate factor of 4 in the ground motion for the range of values in the PSRV for a given return period.

The range between the 15th and the 85th percentile hazard curves represents the total uncertainty in estimating the seismic hazard at a site due to two sources of uncertainty:

- o The uncertainty of each expert in the zonation, models and values of the parameters of the analyses

- o The variation in the hazard estimates due to the diversity of opinions between experts.

The latter, or inter-expert variation is an important contributor to the total uncertainty in the estimated hazard. Specifically, the magnitude of uncertainty introduced by the diversity of opinions between experts is of the same order, on the average, as the uncertainty in the hazard due to the uncertainty of an individual expert in the value of the parameters. However, as shown in Section 2.4 at times the uncertainty between experts can be very large.

For a given acceleration value, the range of the median hazard values at all the sites analyzed falls within the 15th-85th percentile range of any one of those sites.

(2) The 50th percentile CPHC appears to be a stable estimator of the seismic hazard at the site. That is, it is the least sensitive to changes in the parameters, when compared to other estimators considered in this study.

(3) The process of estimating the seismic hazard in the EUS is reasonably stable. Comparison with our previous results indicated that there has not been a major shift in results over the past few years, although there have been some significant perturbations in the form of recent occurrences of EUS earthquakes and the completion of several major studies of the seismotectonics of the EUS. In the feedback performed in this study, there were some changes introduced by members of both the Seismicity and GM Panels. However, the computed hazard when aggregated over all experts did not significantly change. However, the introduction of the "new" random vibration models introduced a significant change in the spectral shape by raising the spectral values in the high frequency range and lowering it in the low frequency range.

(4) It is difficult to rank the uncertainties, because zonation and the parameters of the recurrence models are hard to separate. Nevertheless, our results indicate that the uncertainty in zonation, and ground motion models are more significant than the uncertainty associated with the seismicity parameters. The largest contribution to modeling uncertainty comes from the uncertainty of the ground motion. The correction for local site effects is a significant contribution to the overall uncertainty introduced by the ground motion models. However, as already noted, the uncertainty introduced by zonation and recurrence models is also significant and of the same order.

(5) Based on comparisons between the results of our broad generic study and site specific studies, we concluded in Bernreuter et al. (1985) that the scale of our study is adequate. No major differences in zonation or results occurred between our study and site specific studies.

(6) We found, consistent with the conclusions in Bernreuter et al. (1987), that generally earthquakes in the magnitude range 3.75 to 5 would significantly increase the estimated seismic hazard if they were included in the analysis. Thus, it may be important to keep in mind that the CPHCs and CPUHS presented in this study only include the contribution from earthquakes with magnitudes of 5 and greater when assessing the seismic safety of brittle components of nuclear power plant systems, e.g., such as relays. In addition, in light of the discussion given in Section 2.4, it must be kept in mind that the PGA value is not a good estimator of the loading that very stiff components will experience in the EUS. The actual ground motion will be amplified.

(7) We found that the correction for the site's soil category had an important effect on the estimated hazard. In Section 2.2 of Vol. VI we provided approximate correction to be applied to the estimated hazard for rock site to estimate the hazard for shallow soil conditions at the same site. This is useful for sites which have a few structures founded on shallow soil. Later in Vol. VIII we will provide calculations for the sites with multiple soil conditions.

Finally, it is difficult to assess if our results have either a conservative or unconservative bias. We insisted that our panel members not introduce such biases in their inputs and we spent considerable effort in developing a methodology which would allow the experts to properly express their uncertainty without having to introduce some conservative approximations. This was particularly true in the area of regional ground motion modeling and in the incorporation of multiple alternatives to account for any local site amplification of the ground motion.

(8) We found that in general the site soil correction is not a linear operation on the hazard curve. Thus it is, in general, incorrect to modify a hazard curve calculated for a rock site by multiplying by a constant number (i.e., mean or median correction factor) to obtain the hazard curve at the same site for a different soil condition. Performing this incorrect operation could lead to errors in the estimate of the PGA, for a fixed return period, by as much as 10 percent. However, we found that for some sites, multiplying the median hazard curve for rock by the median correction factor would have given approximately the same median hazard curve we obtained by performing the full analysis with our probabilistic correction factors. Unfortunately, at the present time, we have not been above to develop criteria to identify when performing such operation is correct.

(9) Although the soil site correction is not region dependent, we found that other complex interactions, with zonation seismicity and ground motion models, made the site correction actually region dependent.

(10) We found that the input from some experts lead to either high or low estimates of the hazard at most sites. In particular G-Expert 5's input lead to results, in general, higher than when only the other 4 GM Experts' input is used.

We found that the impact from any S-Expert did not show a consistent deviation from the results of all the other S-Experts at all sites, however, the results from some of the S-Experts were found to be either high in some region of the EUS (i.e. S-Expert 2), or low (i.e. Expert 12, especially in the South West and Central U.S.).

Appendix A

References

D.L. Bernreuter, J.B. Savy, R.W. Mensing, J.C. Chen, B.C. Davis, Seismic Hazard Characterization of the Eastern United States, Vol. 1 and Vol. 2, LLNL UCID-20421, Vol. 1 and Vol 2. (April 1985).

D.L. Bernreuter, J.B. Savy and R.W. Mensing, Seismic Hazard of the Eastern United States: Comparative Evaluation of the LLNL and EPRI Studies, USNRC Report NUREG/CR-4885 (1987).

Lee, V.W. and M.D. Trifunac (1985), Attenuation of Modified Mercalli Intensity for Small Epicentral Distances in California, University of Southern California Report CE85-01.

Newmark, N.M. and Hall, W.J., Development of Criteria for Seismic Review of Selected Nuclear Power Plants, Nuclear Regulatory Commission Report NUREG/CR-0098, May 1978, 49 p.

Trifunac, M.D. (1986), A Note of the Range of Peak Amplitudes of Recorded Accelerations, Velocities and Displacements with Respect to the Modified Mercalli Intensity, Earthquake Notes 47, pp. 9-24.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Appendix B

Maps of the Seismic Zonation for Each of the 11 S-Experts

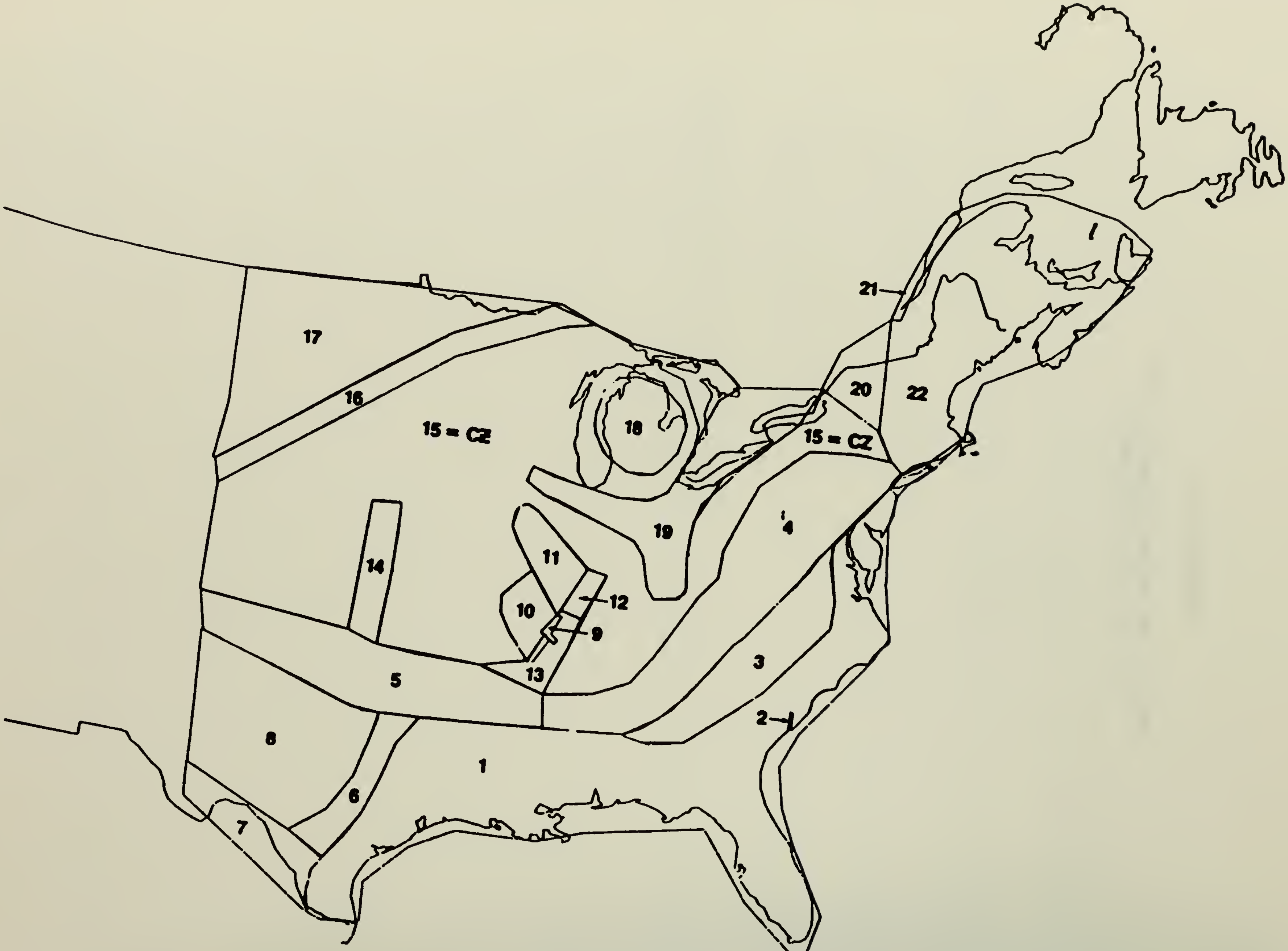


Figure B1.1 Seismic zonation base map for Expert 1.

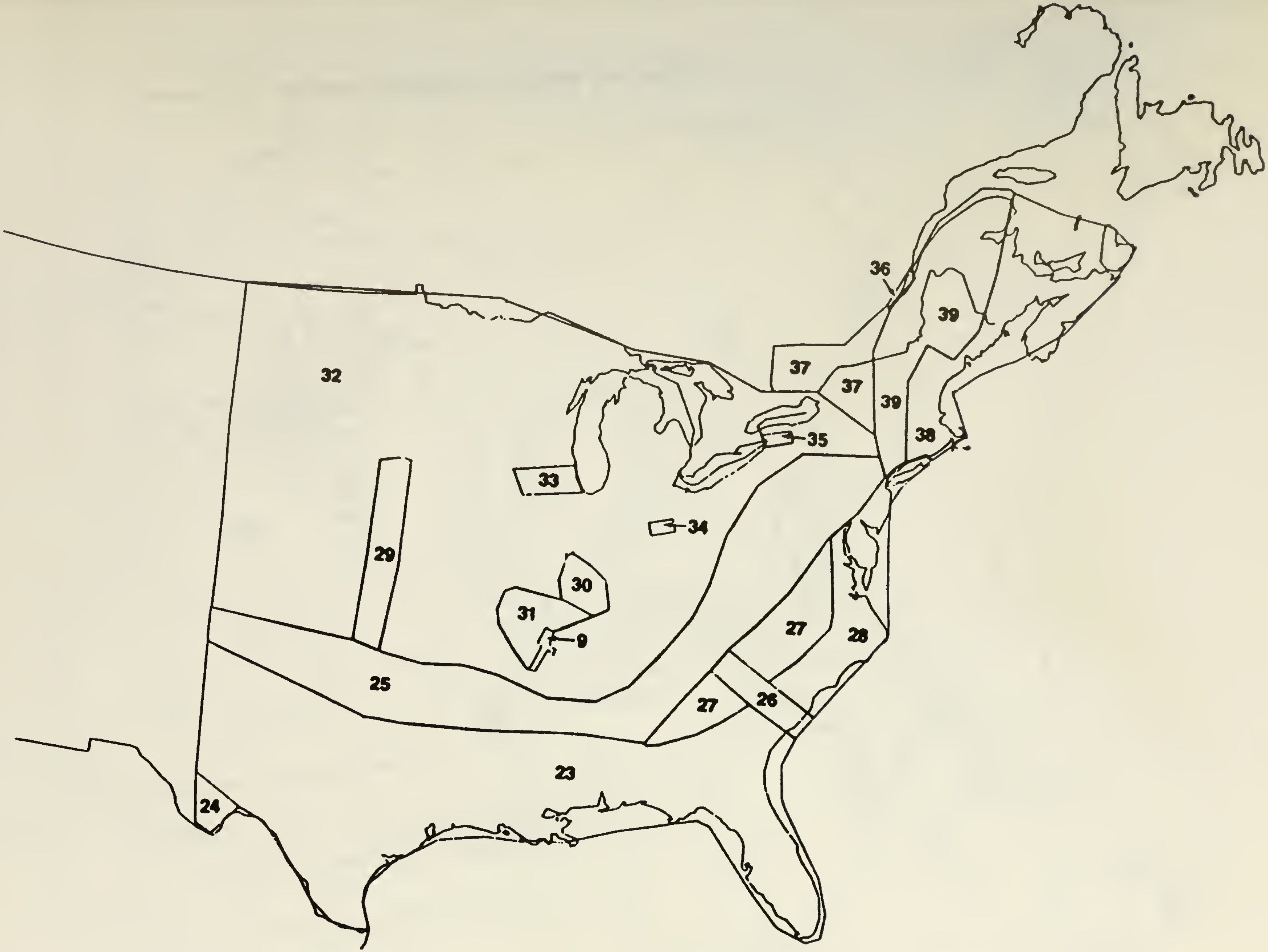


Figure B1.2 Map of alternative seismic zonation to Expert 1's base map.

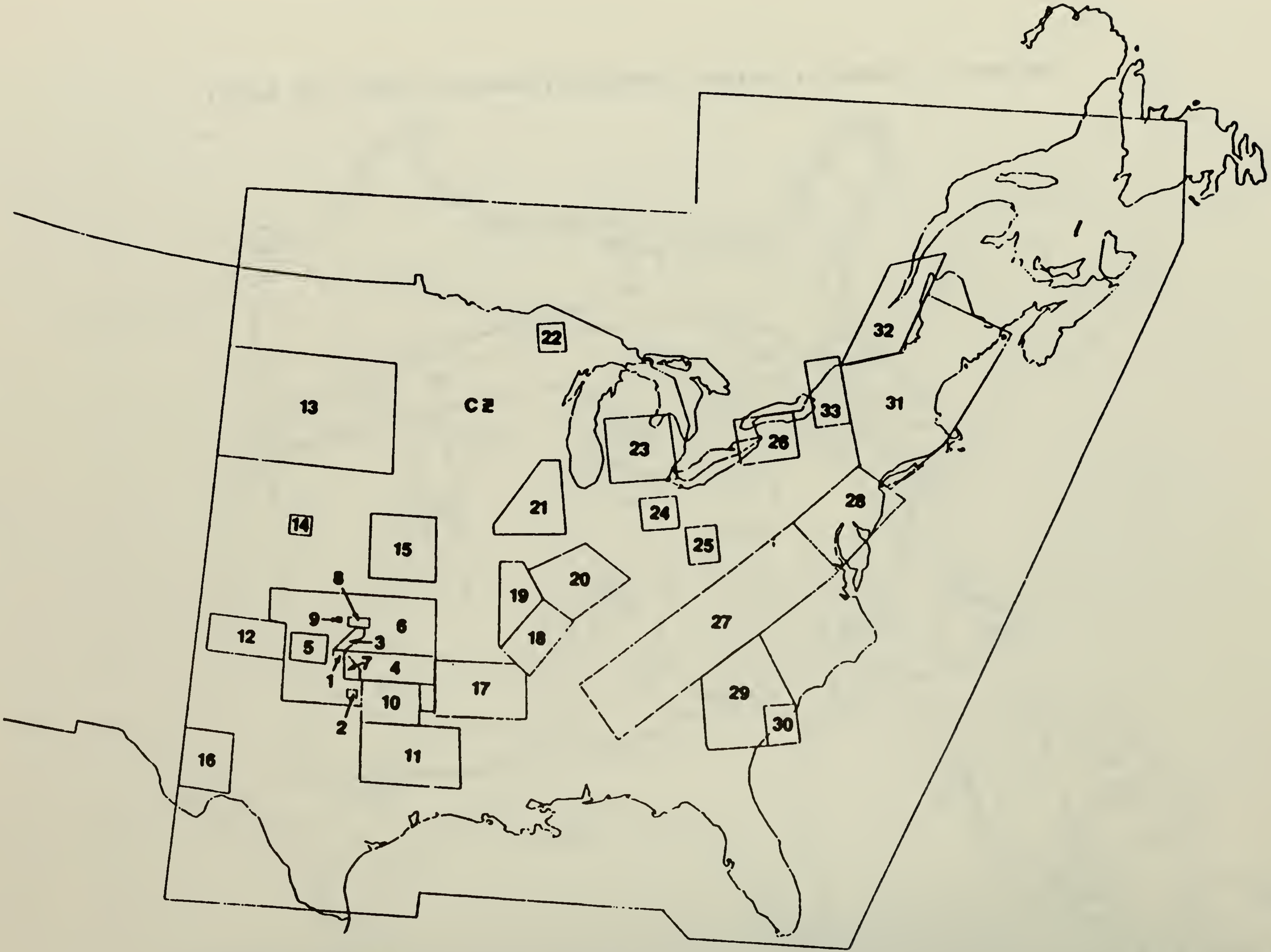


Figure B2.1 Seismic zonation base map for Expert 2.

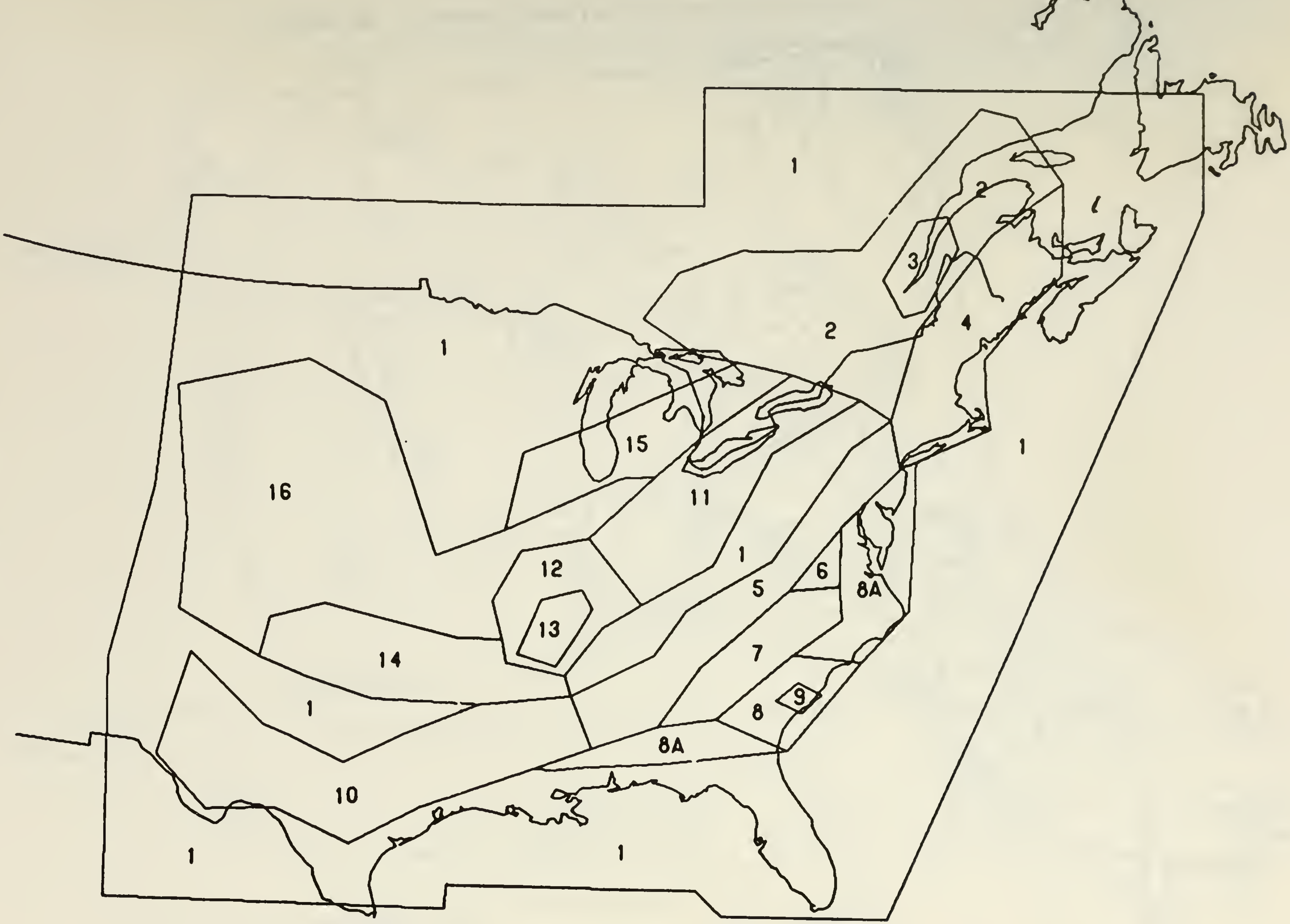


Figure B3.1 Seismic zonation base map for Expert 3.

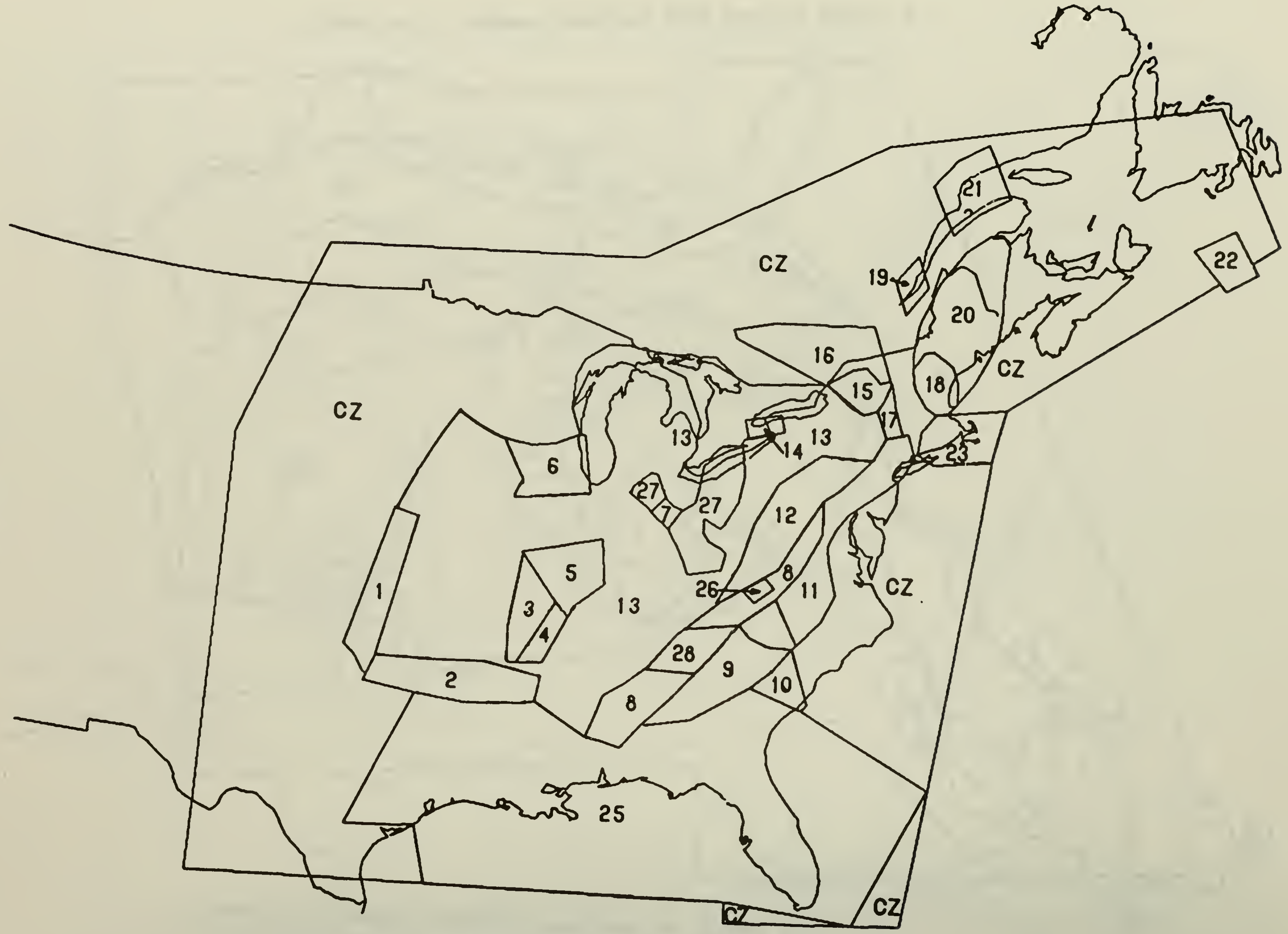


Figure B4.1 Seismic zonation base map for Expert A

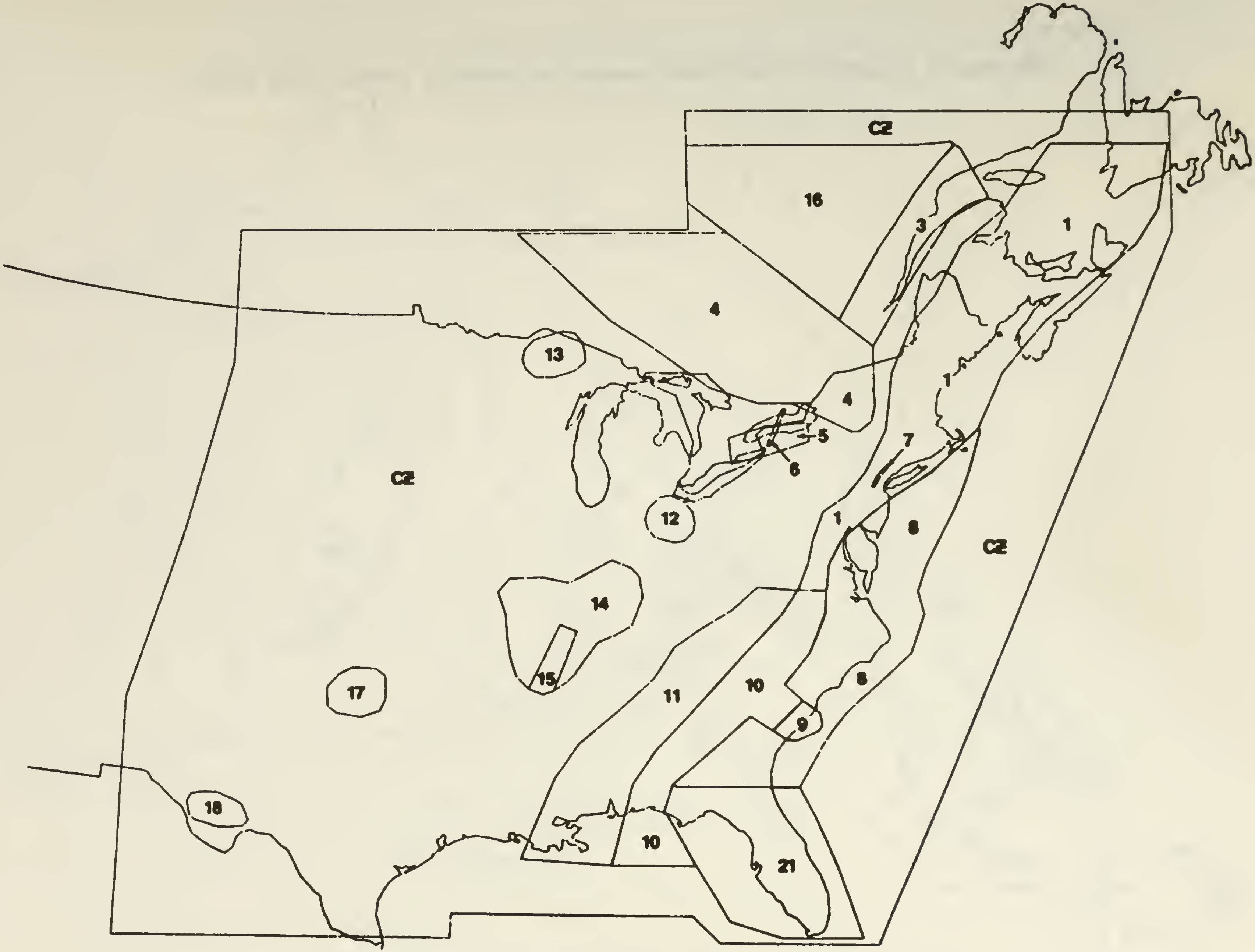


Figure B5.1 Seismic zonation base map for Expert 5

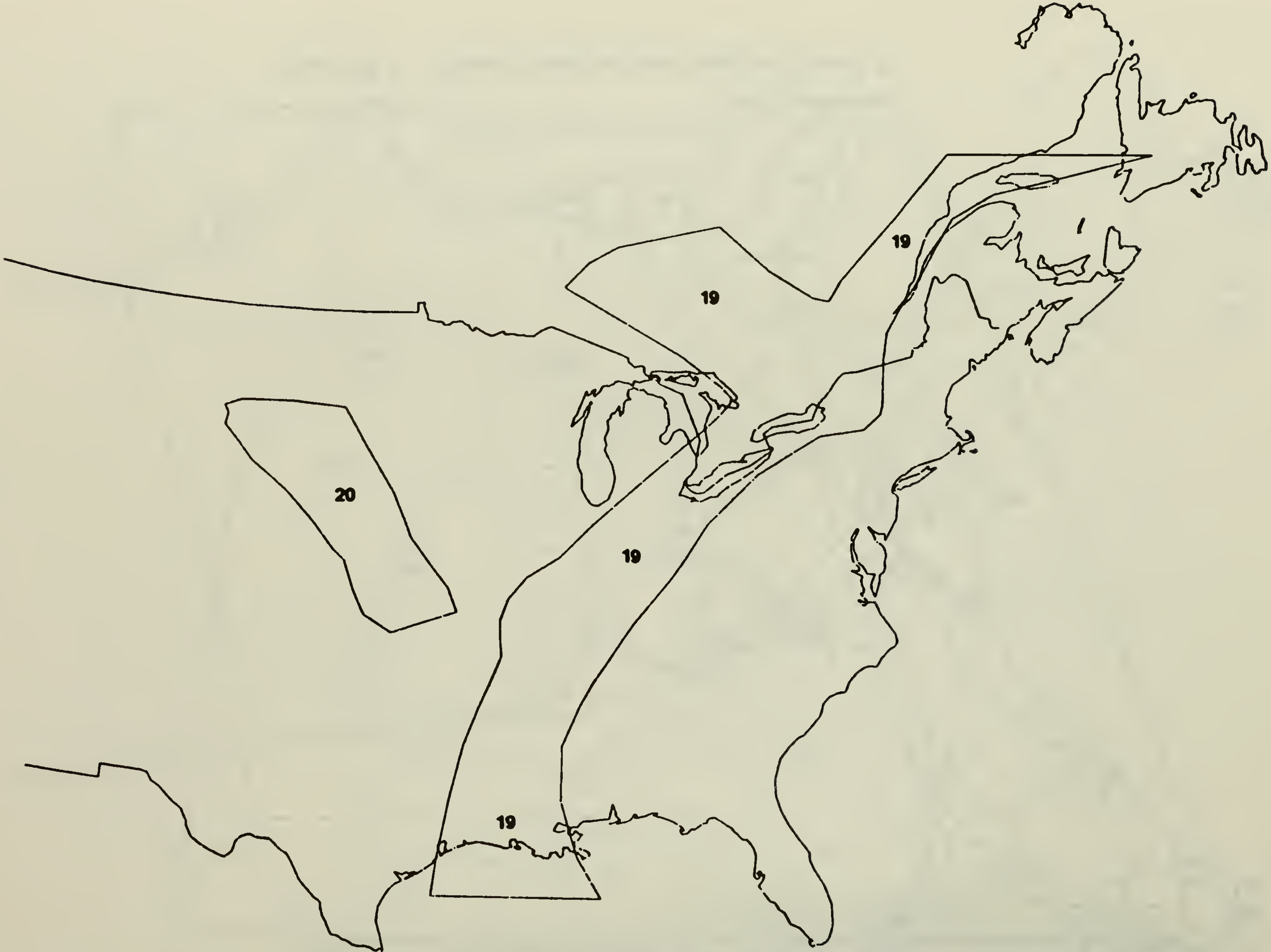


Figure B5.2 Map of alternative seismic zonations to Expert 5's base map.

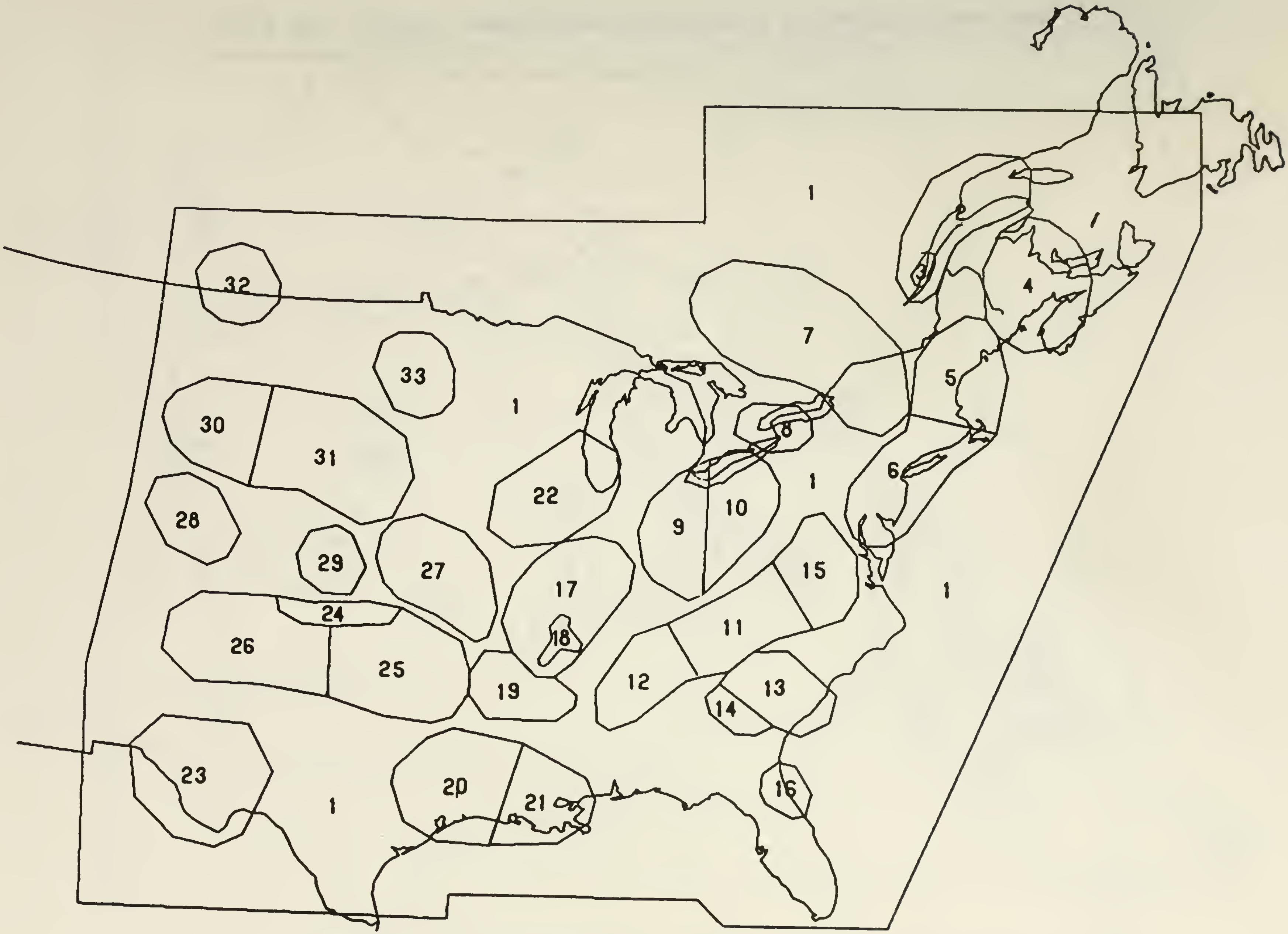


Figure B6.1 Seismic zonation base map for Expert 6

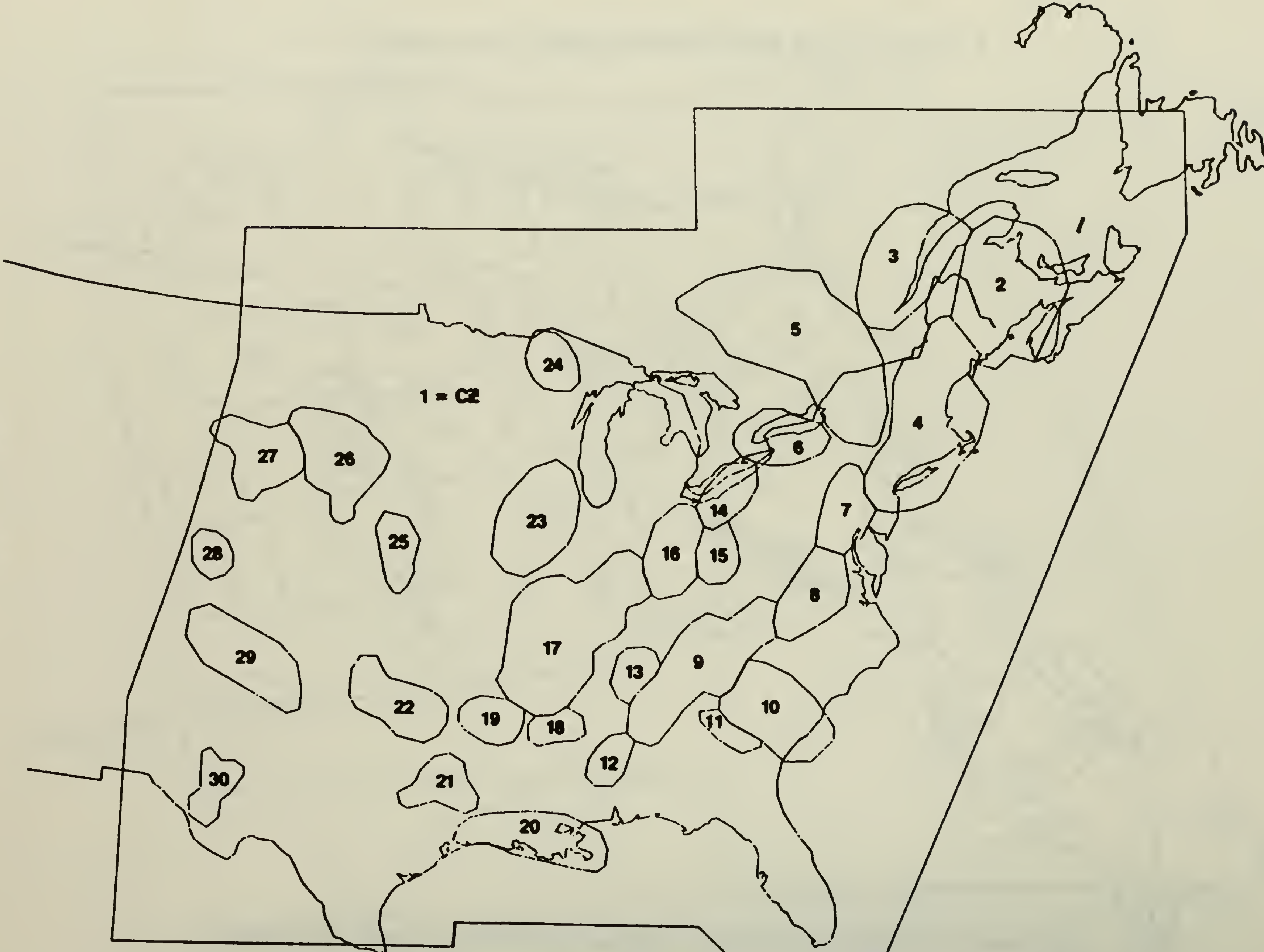


Figure B6.2 Seismic zonation map alternative 1 to Expert 6's base map.

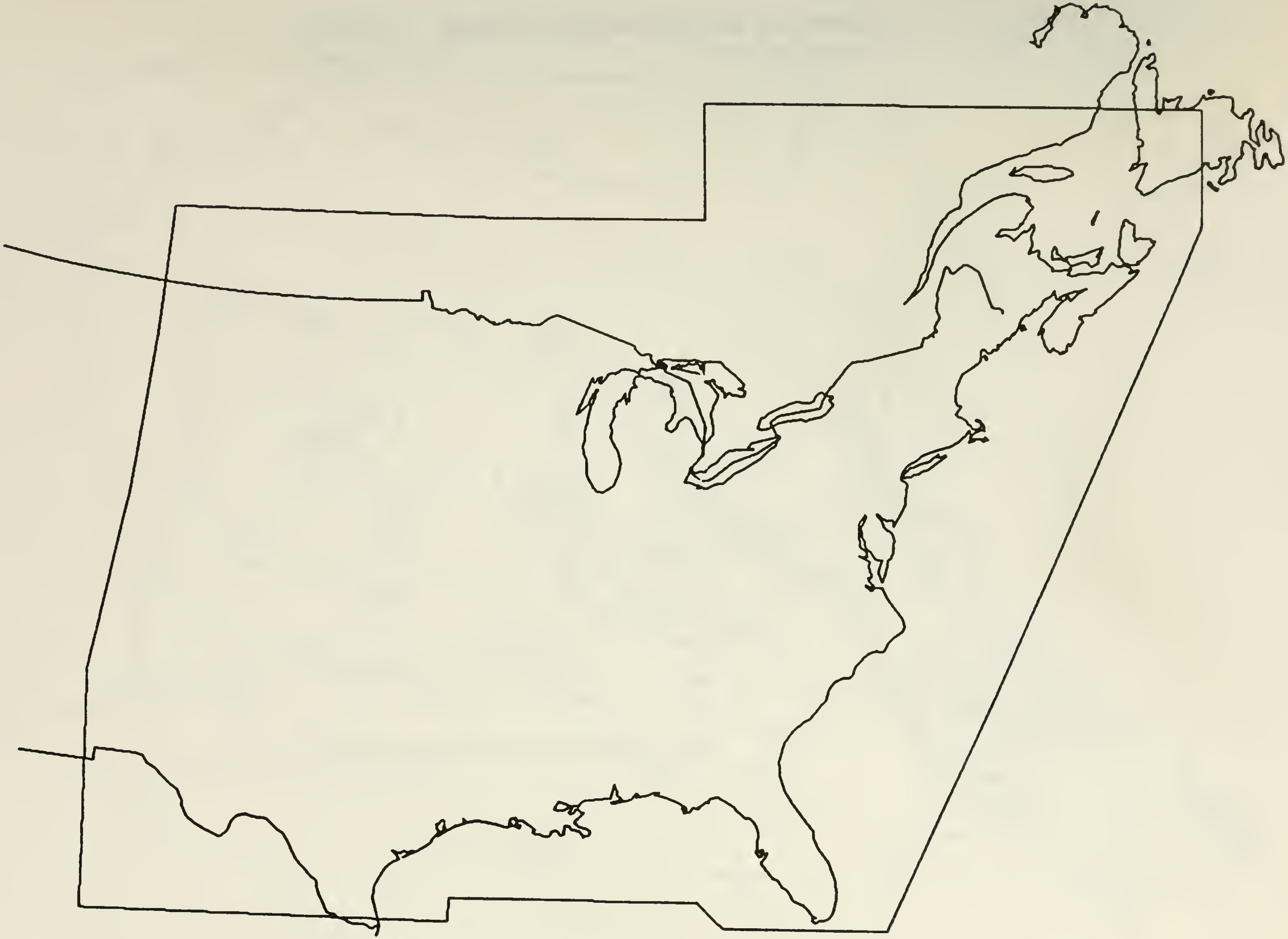


Figure B6.3 Seismic zonation map alternative 2 to Expert 6's base map.

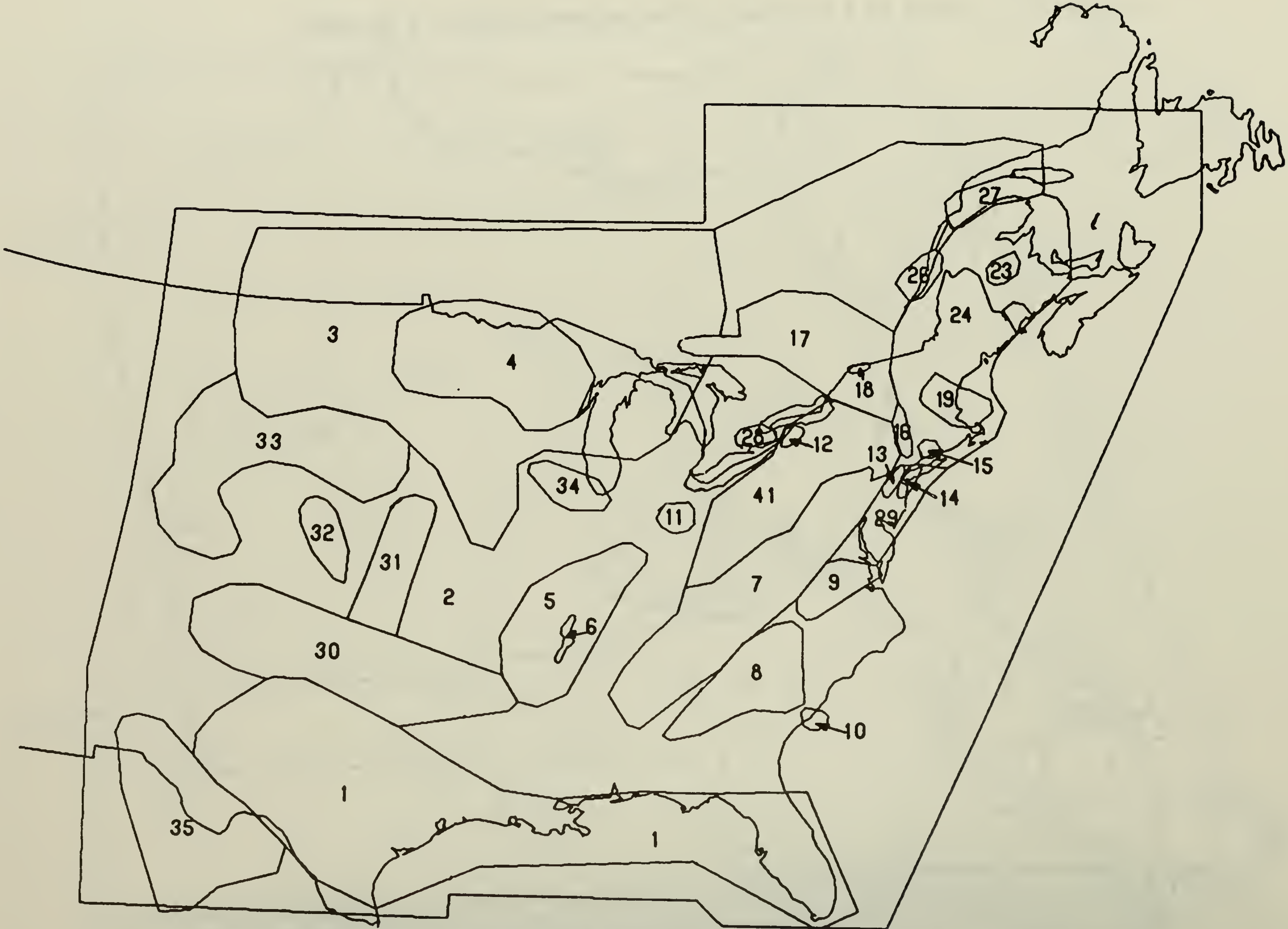


Figure 7.1 Seismic zonation base map for Expert 7.

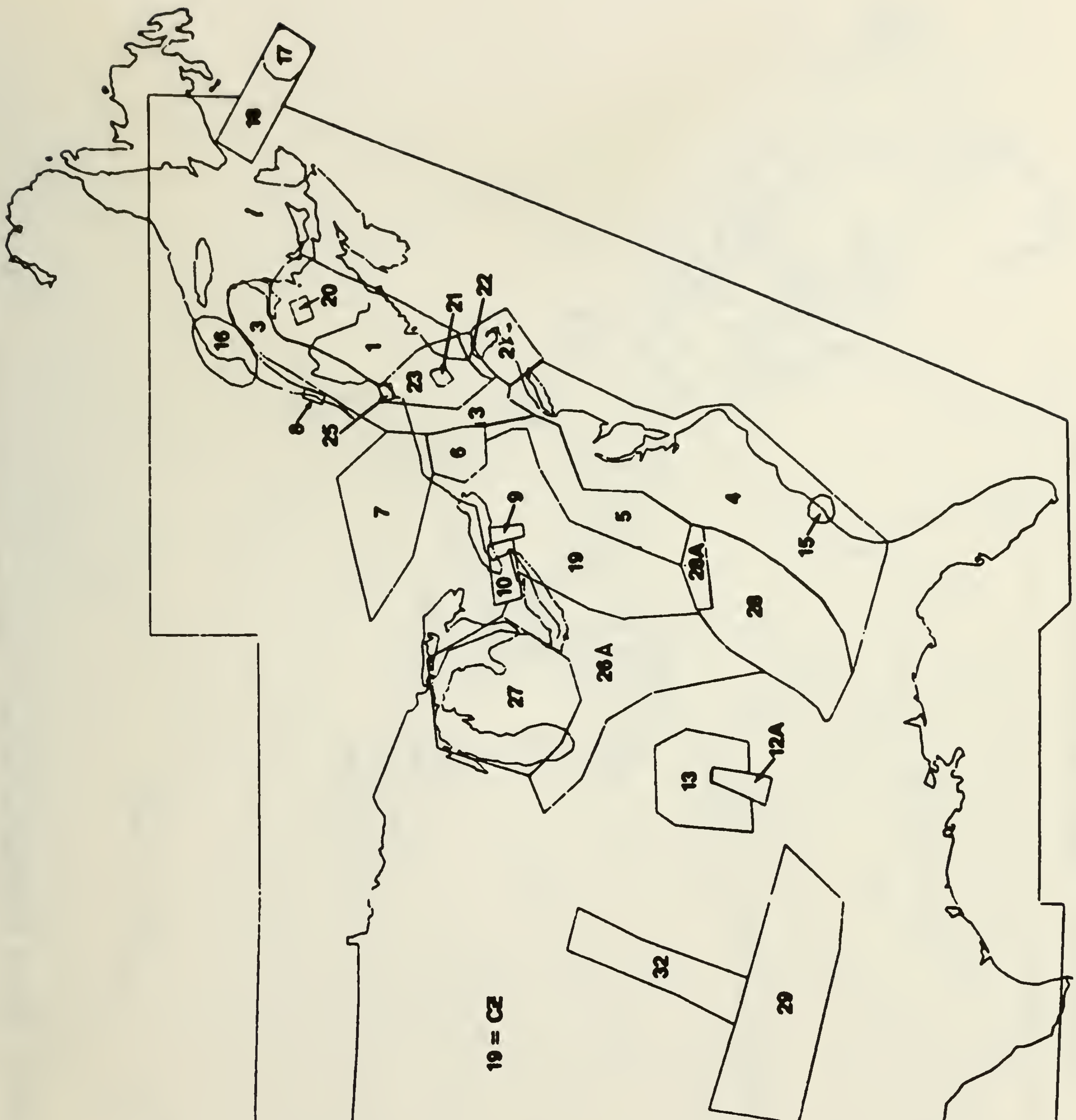


Figure B10.1 Seismic zonation base map for Expert 10.

Figure B10.2 Map of alternative seismic zonations to Expert 10's base map.

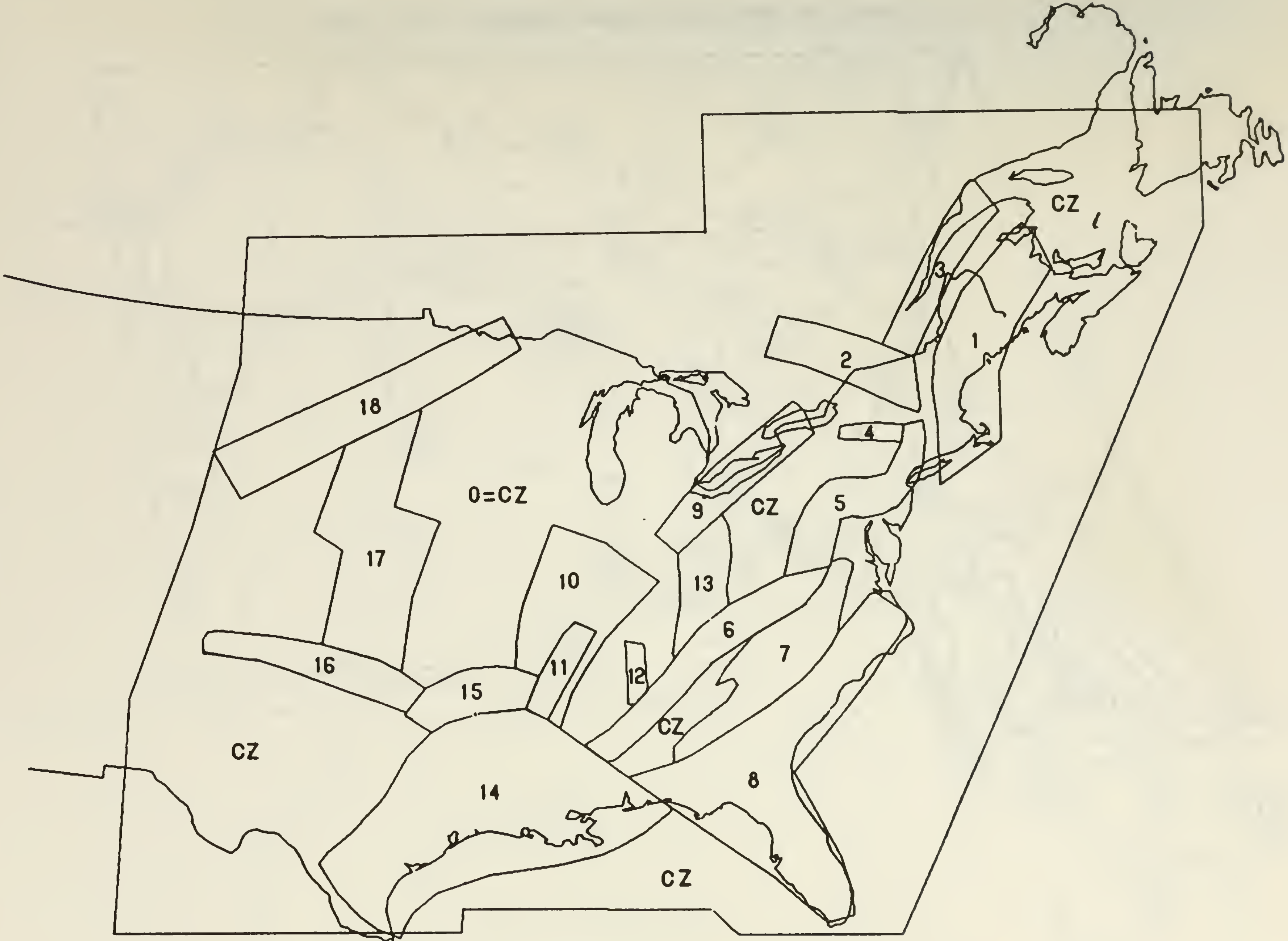


Figure B11.1 Seismic zonation base map for Expert 11.

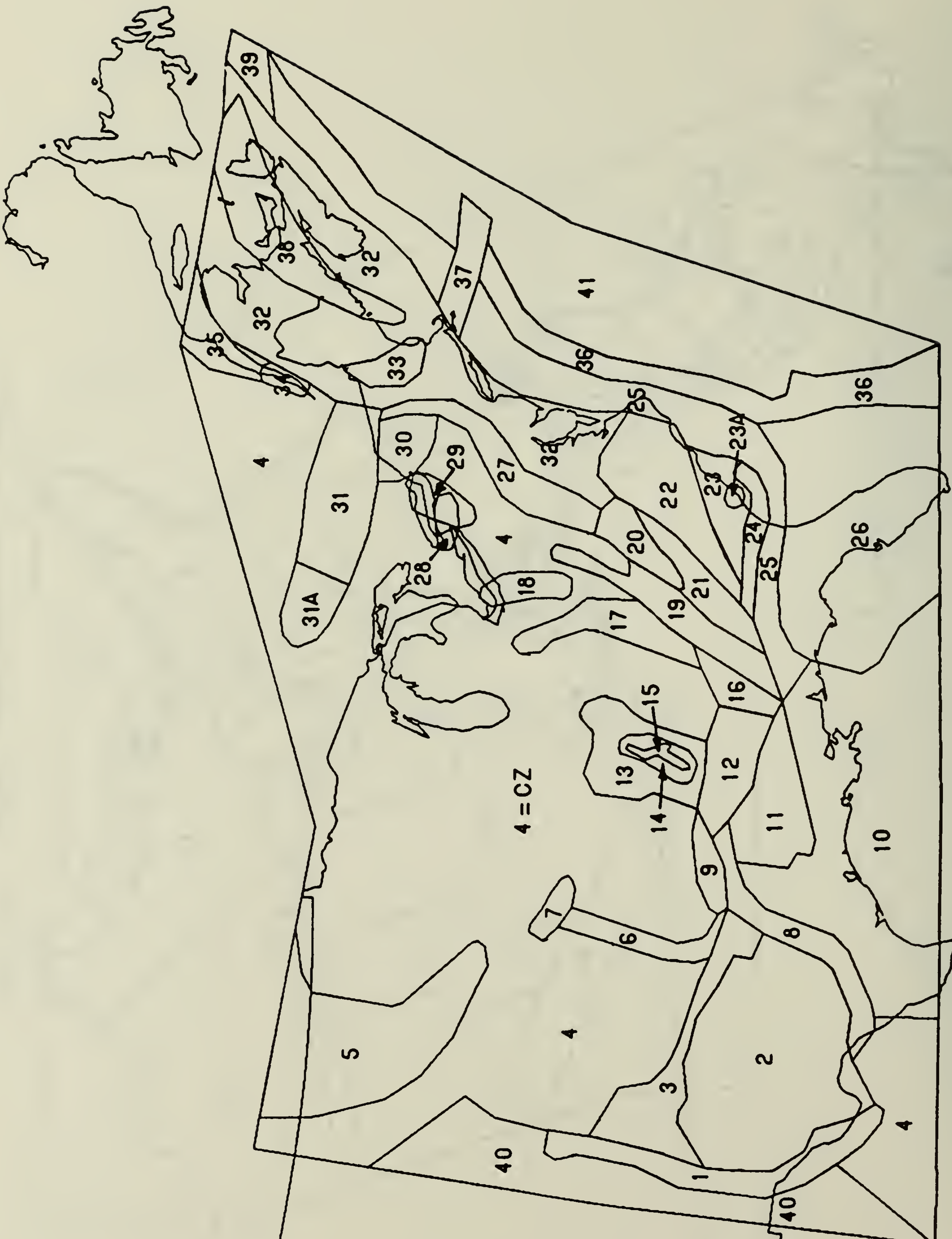


Figure B12.1 Seismic zonation base map for Expert 12.

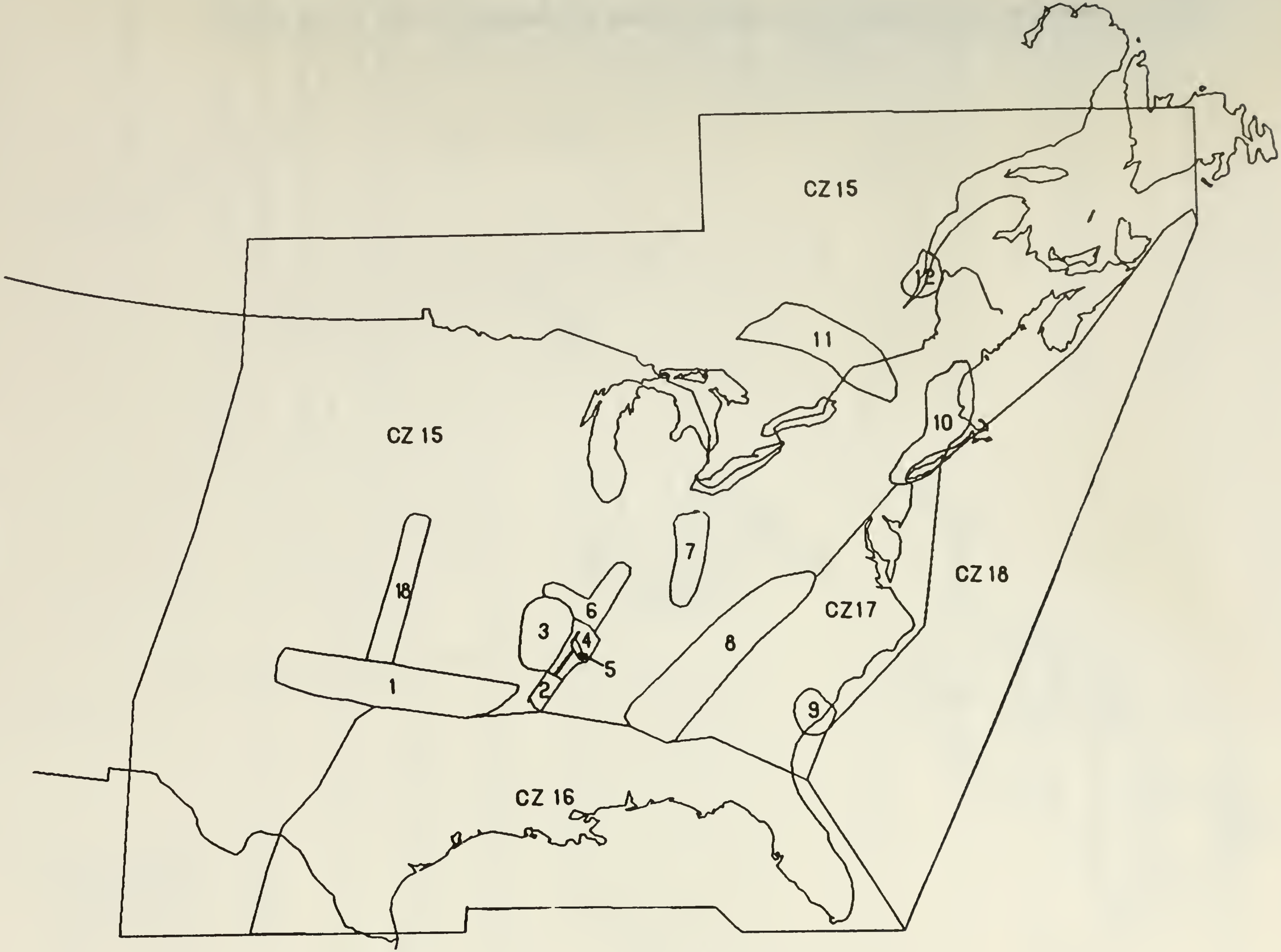


Figure B13.1 Seismic zonation base map for Expert 13.

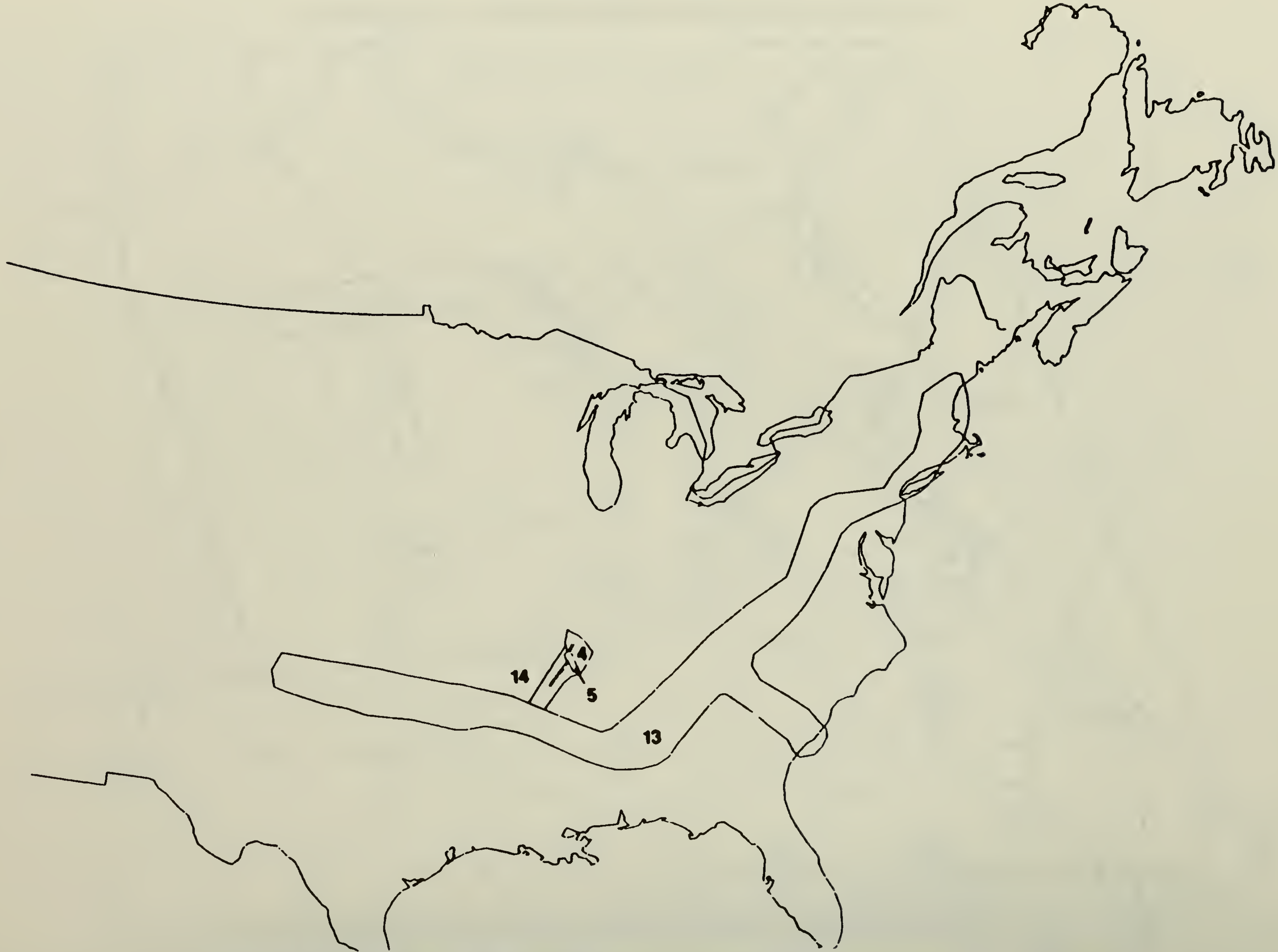


Figure B13.2 Map of alternative seismic zonations to Expert 13's base map.

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol No., if any)
NUREG/CR-5250
UCID-21517
Vol. 6

2. TITLE AND SUBTITLE
Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains
Regional Comparison Between Sites, Site Effects, General Discussion, and Conclusions

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
November	1988

5. AUTHOR(S)
D.L. Bernreuter, J.B. Savy, R.W. Mensing, J.C. Chen

6. DATE REPORT ISSUED

MONTH	YEAR
January	1989

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Lawrence Livermore National Laboratory
P.O. Box 808, L-197
Livermore, California 94550

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
A0448

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Engineering and System Technology
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT
Technical

b. PERIOD COVERED (Inclusive dates)
October 1986-October 1988

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

The EUS Seismic Hazard Characterization Project (SHC) is the outgrowth of an earlier study performed as part of the U.S. Nuclear Regulatory Commission's (NRC) Systematic Evaluation Program (SEP). The objectives of the SHC were: (1) to develop a seismic hazard characterization methodology for the region east of the Rocky Mountains (EUS), and (2) the application of the methodology to 69 site locations, some of them with several local soil conditions. The method developed uses expert opinions to obtain the input to the analyses. An important aspect of the elicitation of the expert opinion process was the holding of two feedback meetings with all the experts in order to finalize the methodology and the input data bases. The hazard estimates are reported in terms of peak ground acceleration (PGA) and 5% damping velocity response spectra (PSV).

A total of eight volumes make up this report which contains a thorough description of the methodology, the expert opinion's elicitation process, the input data base as well as a discussion, comparison and summary volume (Volume VI).

Consistent with previous analyses, this study finds that there are large uncertainties associated with the estimates of seismic hazard in the EUS, and it identifies the ground motion modeling as the prime contributor to those uncertainties.

The data bases and software are made available to the NRC and to the public uses through the National Energy Software Center (Argonne, Illinois).

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
Seismic hazard, Eastern U.S., ground motion

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17. NUMBER OF PAGES

18. PRICE

*U.S. GOVERNMENT PRINTING OFFICE:1989-241-590:80330

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
PERMIT No. G-67